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Effects of Increased Commercial Navigation Traffic on Freshwater Mussels in the Upper Mississippi River: 1994 Studies

by Andrew C. Miller, Barry S. Payne

Prepared for U.S. Army Engineer District, St. Louis

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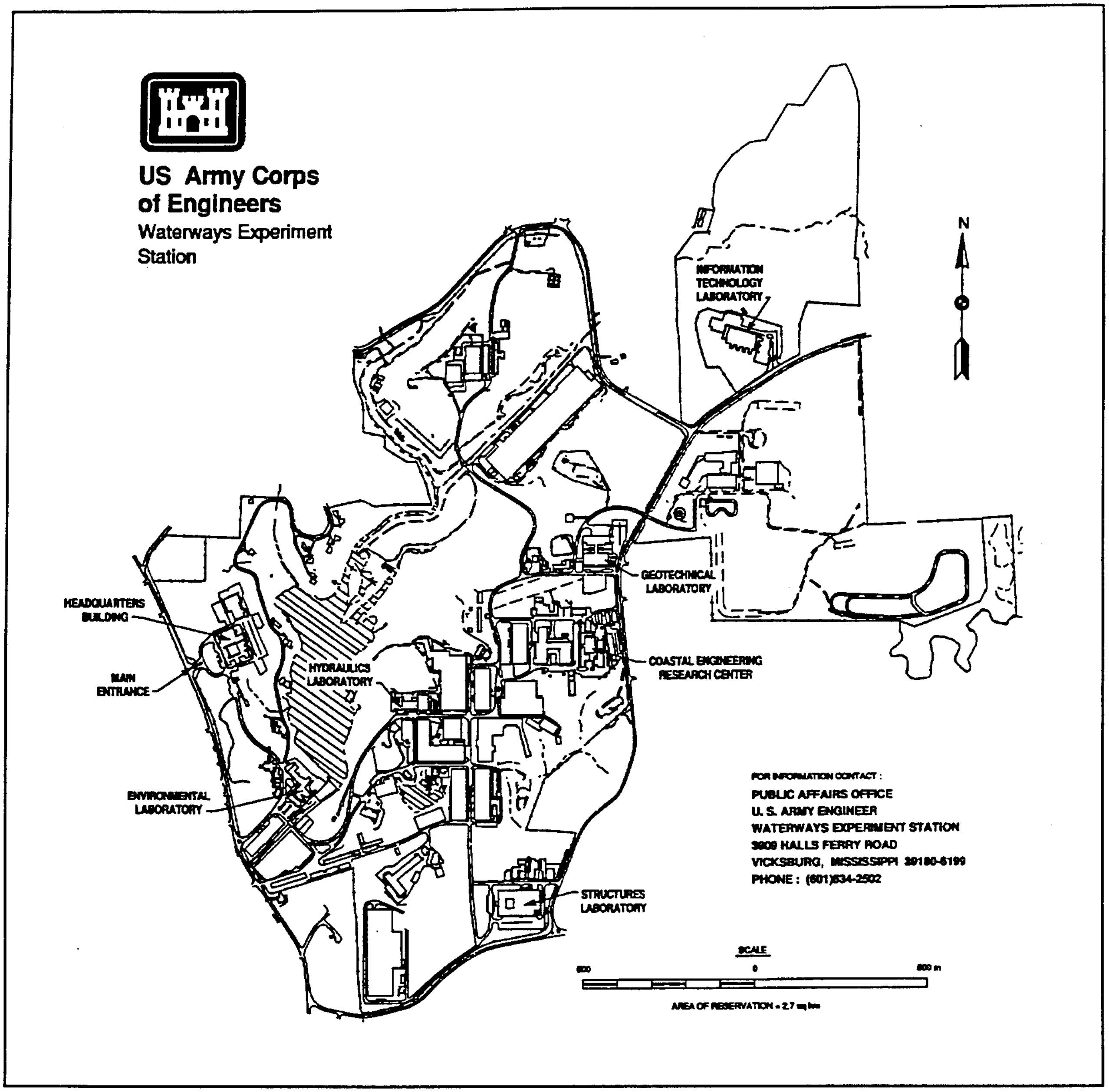

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Contents

Preface

In accordance with the Endangered Species Act, Section 7, Consultation, personnel from the U.S. Army Engineer District, St. Louis, and the U.S. Fish and Wildlife Service (USFWS) determined that a monitoring program should be initiated in the upper Mississippi River to assess the effects of existing and projected future increased traffic levels on freshwater mussels including the endangered Higgins' eye mussel, *Lampsilis higginsi*. Concern had been expressed by the USFWS and other agencies that projected increases in commercial traffic resulting from completion of the Melvin Price Locks and Dam, Second Lock Project (formally known as Locks and Dam 26) at Alton, IL, could negatively affect freshwater mussels. In 1988, the St. Louis District contracted with the U.S. Army Engineer Waterways Experiment Station (WES) to initiate these studies. The purpose of the 1988 studies was to identify sample sites for future work. Detailed studies were then conducted from 1989 to 1994. This report describes results from 1994.

Divers for this study were Messrs. Larry Neill, Kevin Chalk, Rob James, Jeff Montgomery, and Johnny Buchannan from the Tennessee Valley Authority (TVA). Mr. B. Will Green, Mr. Travis Whiting, and Dr. David Beckett, University of Southern Mississippi, Hattiesburg, MS, assisted in the field. Diving inspectors were Ms. Katherine Meadows and Mr. Stanley Zurweller, St. Louis District, and Mr. David Rogillio, WES. Ms. Geralline Wilkerson, Jackson State University, Jackson, MS, prepared all figures except maps; Ms. Erica Hubertz, University of West Florida, Pensacola, FL, and Mr. David Armistead, Millsaps College, Jackson, MS, identified and measured mussels. Comments on an early draft of this report were provided by Mr. Dan Ragland and Ms. Sherrie Zenk-Reed, St. Louis District. Mr. Robert Read of the Wisconsin Department of Natural Resources, recently deceased, first introduced the authors to the molluscan resources of the east channel and donated his time to assist at this location through 1993. Foul weather and safety gear was provided by TVA.

Dr. John W. Keeley was Director, Environmental Laboratory (EL), WES; Dr. Conrad J. Kirby was Chief, Ecological Research Division (ERD), EL; and Dr. Alfred F. Cofrancesco was Chief of the Aquatic Ecology Branch (AEB), ERD. Authors of this report were Drs. Andrew C. Miller and Barry S. Payne, AEB.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

Background

Operation of the second lock at the Melvin Price Locks and Dam (formerly the Locks and Dam 26 (Replacement) project) will increase the capacity for commercial navigation traffic in the upper Mississippi River (UMR). Personnel from conservation agencies have expressed concern that physical effects of vessel movement could adversely affect freshwater biota in the UMR. Specifically, changes in water velocity at the substratum-water interface and sediment scour as a result of propeller wash from commercial vessels could detrimentally affect freshwater mussels (Mollusca: Unionidae), including *Lampsilis higginsi*, listed as Endangered by the U.S. Fish and Wildlife Service (USFWS) (1993). In accordance with the Endangered Species Act, Section 7, Consultation, personnel from the U.S. Army Engineer District, St. Louis, and the USFWS determined that a monitoring program should be initiated to assess the effects of projected traffic levels on freshwater mussels including *L. higginsi*. Other agencies that participated in the development of this monitoring program included the U.S. Army Engineer Divisions, Lower Mississippi Valley and North Central; U.S. Army Engineer Districts, St. Paul and Rock Island; and local State conservation agencies.

A reconnaissance survey to choose sample sites and to conduct preliminary sampling was conducted in 1988 (Miller et al. 1990) and also in 1989 (Miller and Payne 1991). Detailed quantitative and qualitative studies at selected mussel beds were initiated in 1989 and continued through 1994. This report contains an analysis of data collected in July 1994, the sixth and final year of the monitoring program.

Study Design

This research was designed to obtain information on changes in water velocity and suspended solids near the substrate-water interface when vessels pass dense and diverse mussel beds in the UMR. As part of these physical studies, important biotic parameters (species richness, species diversity, density, growth rate, and population structure of dominant mussel species) were monitored. Physical and biological data were collected at a farshore

(experimental) and nearshore (reference) site within each mussel bed. Experimental sites were located close to the navigation channel and affected by vessel passage. Reference sites were located as far as possible from the channel and affected to a lesser extent by vessel passage, but still on the mussel bed. The intent was to couple empirical data from physical and biological studies to make predictions of the effects of vessel passage on freshwater mussels.

The primary objective was to determine whether commercial navigation traffic negatively affects *L. higginsi*. This was accomplished by collecting information on all species of bivalves and applying results to *L. higginsi*. This surrogate species concept was used since it is extremely difficult to obtain information on density, recruitment, etc., for uncommon species such as *L. higginsi*. In addition, intensive collecting could be detrimental to the continued existence of this species. The following six parameters, considered to be indicative of the health of a mussel bed, were used to determine if movement of commercial navigation vessels negatively affects freshwater mussels.

a. Decrease in density of five common-to-abundant species.

b. Presence of *L. higginsi* (if within its range).

c. Live-to-recently-dead ratios for dominant species.

d. Loss of more than 25 percent of the species.

e. Evidence of recent recruitment.

f. A significant change in growth rates or mortality of dominant species.

Selected studies were done at each bed each year of the monitoring project. Quantitative techniques were used to collect mussels at each bed every second year. Qualitative methods were used every year or every second year to collect mussels and search for endangered species. Growth rates of dominant species were determined at most beds. These data were collected yearly during a period when traffic levels were not expected to increase. After 1994, biological and physical data will be collected at each bed once every 5 years. This will be done until traffic levels have increased as a result of completion of the Melvin Price Locks and Dam by an average of one tow per day above 1990 levels in the pool where monitoring takes place. Studies will then resume at the original rate (annually) and continue until 2040, the economic life of the project. Results of studies from each year were reviewed annually to determine the need for altering sampling protocol. A schedule of studies to be conducted at each mussel bed appears in Table 1. Information from the previous years is available: 1988 (Miller et al. 1990), 1989 (Miller and Payne 1991), 1990 (Miller and Payne 1992), 1991 (Miller and Payne 1993), 1992 (Miller and Payne 1994), and 1993 (Miller and Payne 1995).

Purpose and Scope

The purpose of this monitoring program (1988-94) was to obtain baseline data on physical (water velocity and suspended solids) and biological conditions (density, species richness, relative species abundance, population demography of dominant species, etc.) at five mussel beds between River Miles (RMs) 299 and 635 in the UMR. This report describes results of sampling at all five mussel beds in July 1994, the final year of the project.

2 Study Area and Methods

Study Area

The UMR was once a free-flowing, braided, pool-riffle habitat with side channels, sloughs, and abandoned channels. This riverine habitat was altered as a result of passage of the Rivers and Harbors Act of 3 July 1930, which authorized the U.S. Army Corps of Engineers to construct a navigation channel with a minimum depth of 9 ft[1] and a minimum width of 300 ft. Development of this navigation channel, which included construction of locks, dams, dikes, wing dams, and levees, converted the river to a series of run-of-the-river reservoirs, characterized by relatively slow-moving water and extensive adjacent lentic habitats. Typically, the upper reaches of pools in the UMR have comparatively high water velocity and coarse substratum, whereas the lower reaches are more lake-like with deep, low-velocity water and fine-grained sediments (Eckblad 1986).

Study Sites

In 1988, preliminary data on physical and biological conditions were collected at mussel beds in Pools 26, 25, 24, 19, 18, 17, 14, 10, and 7. In 1989, additional preliminary studies were conducted in Pools 12 and 13. Both qualitative and quantitative sampling techniques were employed to determine if mussel beds identified from resource maps (Peterson 1984) were suitable for detailed study. Based on information from these surveys, a list of suitable mussel beds suitable for more detailed study was prepared.

Personnel of the St. Louis District, the U.S. Army Engineer Waterways Experiment Station (WES), and the USFWS participated in the final selection process. Beds chosen for detailed study are located at the following river miles (Figure 1):

[1] A table of factors for converting non-SI units of measurement to SI units is presented on page vi.

Pool	RM
24	299.6 RDB
17	450.4 RDB
14	504.8 LDB
12	571.5 RDB
10	635.2 RDB (Main Channel)
Note: RDB = right descending bank; LDB = left descending bank.	

Each bed is several miles long; exact location of sampling sites on beds often varied slightly from year to year. A brief description of sites sampled in 1994 appears below. A summary of sampling conducted in previous years appears in Table 2.

Pool 24

The mussel bed in Pool 24 is located on the right descending bank (RDB) approximately 1.5 miles downriver of Lock and Dam 22 (Figure 2). A series of wing dams on the left descending bank (LDB) direct water across the channel and toward the mussel bed. Commercial traffic must move along the RDB when approaching or exiting Lock and Dam 22. Substrate at this location consists of slab rock, coarse gravel, and sand. Although *L. higginsi* has never been found in Pool 24, this bed contains a dense and diverse assemblage of mussels. This location was included in this project so that representative data would be collected in the lower portion of the UMR. In 1994, 24 samples were obtained using qualitative methods, and 60 total substratum samples (20-ℓ buckets filled with sediment) were collected (Tables 2 and 3).

Pool 17

The mussel bed in Pool 17 is at RM 450.4 immediately downstream of a small creek and a wood duck box (Figure 3). Quantitative samples were first collected here in 1988 (Table 2). The substratum is fine-grained material with little gravel and some detritus. There are commercial loading facilities immediately upriver and downriver of this location. In 1994, 60 quantitative and 24 qualitative samples were collected (Tables 2 and 3).

Pool 14

An extensive mussel bed is located in the lower portion of Pool 14 on the LDB (Figure 4). This bed supports a dense and diverse assemblage of mussels including *L. higginsi*. Substratum consists of silt, sand, and gravel. In this

study year (1994), 48 qualitative samples and 60 total substratum samples were taken (Tables 2 and 3).

Pool 12

The site in Pool 12 is located at RM 571.5 on the RDB (Figure 5). The mussel bed is long and narrow and located on the RDB of the river immediately downriver of a sharp left turn coming downriver. Commercial vessels moving either upriver or downriver must approach the RDB where the mussel bed is located as they enter or exit the turn. In 1994, 60 quantitative and 36 qualitative samples were taken.

Pool 10

Near Prairie du Chien, Wisconsin, the UMR splits into an east and west or main channel (Figure 6). The east channel is slightly less deep and not as wide as the main channel, although it is navigable. Sediments in both the east and main channel consist of sand and silt with less than 5-percent gravel by weight. Numerous sloughs, aquatic plant beds, and islands characterize much of Pool 10. The study site for this monitoring program is in the west or main channel of the UMR. Sixty quantitative total substratum samples were collected during this year. No qualitative samples were collected; instead, additional samples were obtained with a suction dredge (Tables 2 and 3).

Methods

Preliminary reconnaissance

A diver equipped with surface air supply and communication equipment made a preliminary survey of each sample site before detailed studies began. He obtained information on substrate type, water velocity, and presence of mussels. A fathometer was used to measure water depth, and distance to shore was determined with an optical range finder.

Qualitative collections

Qualitative samples were obtained by two divers working simultaneously. The pair of divers was given a total of 12 nylon bags and instructed to place about 5 mussels in three bags and about 20 mussels in the remaining nine bags. Divers attempted to collect only live mussels, although occasionally dead shells were taken that were later discarded. Collecting was done mainly by feel since water visibility was poor. Mussels were brought to surface, identified, and counted. Selected mussels were shucked and retained for voucher. Additional specimens were preserved in 10-percent buffered formalin

and returned to the laboratory for analysis of physical condition (ratios of shell length to tissue dry mass, etc.). Unneeded mussels were returned to the river unharmed. See Table 3 for a summary of samples collected in 1994.

Quantitative sampling

At each nearshore or farshore site, ten 0.25-m^2 quadrat samples were obtained at each of three subsites separated by 5 to 10 m. At each subsite, quadrats were placed approximately 1 m apart and arranged in a 2 by 5 matrix. A diver removed all sand, gravel, shells, and live molluscs within the quadrat. It usually took 5 to 10 min to clear the quadrat to a depth of 10 to 15 cm. All material was sent to the surface in a 20-ℓ bucket, taken to shore, and sieved through a nested screen series (finest screen with apertures of 6.4 mm) and picked for live organisms. All bivalves were identified, and total shell length (SL) was measured to the nearest 0.1 mm. All *L. higginsi* were returned to the river unharmed. Some of the bivalves were measured in the evening then returned to the river the next day. Bivalves that could not be processed during the survey were preserved in 10-percent buffered formalin and taken to WES for analysis. Notes were made on the number of "fresh dead mussels" (defined as dead individuals with tissue still attached to the valves).

Shells of voucher specimens collected using qualitative or quantitative methods were placed in plastic zipper-lock bags. Mussels not needed for voucher were returned to the river. Methods for sampling mussels are based on techniques described in Miller and Nelson (1983); Isom and Gooch (1986); Kovalak, Dennis, and Bates (1986); Miller and Payne (1988); Miller et al. (1994); and Wilcox, Anderson, and Miller (1994). Mussel identification was based on taxonomic keys and descriptive information in Murray and Leonard (1962); Parmalee (1967); Starrett (1971); and Burch (1975). Taxonomy is consistent with Williams et al. (1992).

Data analysis

All bivalve data (lengths, weights, etc.) were entered on a spreadsheet and stored in ASCII files. Summary statistics were calculated using functions in the spreadsheets or with programs written in BASIC or SAS (Statistical Analysis System). All computations were accomplished with an IBM or compatible personal computer. Biological and physical data were plotted directly from ASCII files using a Macintosh SE computer and laser printer.

3 Results

Sediment Grain-Size Distribution

Grain-size distribution was analyzed from each sediment sample collected quantitatively and picked for live mussels on the shore (see Figures 7-12). The bed in Pool 24 was characterized by dominance of large-sized particles (>34.0 mm in diameter, see Figure 7). Coarse gravel and cobble represented approximately 40 to 50 percent of the sample. Fine-grained sediments, less than 6.35 mm in diameter, comprised 20 to 30 percent of the sample. Moderate mussel densities at this bed are probably the result of the higher percentage of larger particles that reduce the available area of river bottom for large and small mussels.

In contrast to the mussel bed in the upper reach of Pool 24, the nearshore site at the mussel bed in Pool 17 is characterized by dominance of fine-grained particles, less than 6.35 mm (Figure 8). When compared with the nearshore site, the farshore location had greater percentage of large-sized particles. Fine sand and silt (less than 6.35 mm in diameter) comprised approximately 50 percent of the samples.

Sediment composition in mussel beds in Pools 14 and 12 was similar and dominated by fine-grained sands and silt (Figures 9 and 10). There were little to no differences in grain size based on distance to shore, and sand and silt comprised about 60 percent of the samples.

Approximately 60 percent of the sediments at the nearshore site in the main channel of Pool 10 consisted of gravel and cobble greater than 34 mm in diameter (Figure 11). Sediments at the farshore site consisted of approximately equal percentages of very small and very large particles.

Community and Population Characteristics

A total of 27 species of bivalves were collected in the UMR using qualitative and quantitative methods (Table 4). The list includes two exotic species, the Asiatic clam, *Corbicula fluminea*, and the zebra mussel, *Dreissena*

polymorpha. The former species is common in southern habitats and is rarely collected in the UMR. Zebra mussels were first collected in North America in 1988 and in the UMR in 1991. Since they were first found in 1991, densities have increased substantially. They have only become a notable part of the community during 1993 and 1994.

For the entire survey, exactly 300 quantitative samples yielded slightly over 3,100 bivalves, and 161 qualitative samples yielded 2,559 individuals. Based upon qualitative collections, the threeridge, *Amblema plicata plicata*, dominated the native mussels collected (Table B1). However, this species ranked second in abundance in Pools 24 and 17 where *Leptodea fragilis* and *Ellipsaria lineolata* dominated. In the entire collection obtained with qualitative methods, three species each comprised more than 10 percent and 11 species each comprised between 1 and 10 percent of the total assemblage. Eleven species were considered uncommon, and each comprised less than 1 percent of the total collection.

A more accurate representation of community composition can be obtained by examining the results of quantitative sampling at these beds. Appendix A contains percent abundance and occurrence for mussel beds in Pools 24, 17, 14, 12, and 10. *Truncilla truncata* was dominant (overall 36.2 percent) in Pool 24, Pool 17 (24.6 percent), and Pool 14 (25.1 percent). *Amblema plicata plicata* was dominant at the beds in Pools 12 and 10.

Dominance diversity curves

The percent abundance and percent occurrence of species in a community can be plotted to provide a graphical depiction of relationships among species. Percent abundance and percent occurrence was plotted against the species rank (X-axis) for bivalve communities at the five beds surveyed in the UMR (Figures 12-18). Two plots for each mussel bed were constructed, one with and one without the nonindigenous zebra mussel, *D. polymorpha*.

For all mussel beds considered, the mussel species span three orders of magnitude. Species in the community are relatively evenly distributed for beds in all pools except Pool 10. The strong dominance of *A. p. plicata* in comparison with the other species is illustrated by the slightly greater separation of the two most dominant species in the community (Figure 16). For example, in the main channel, *A. p. plicata* comprises 49 percent, and the next most abundant species, *T. truncata*, comprises less than half this value, approximately 20 percent of the total (see Table A9). By comparison, in Pool 24, the dominant *T. truncata* comprises 36.2 percent of the community. The next most abundant species, *Obliquaria reflexa*, comprises more than half of this value, 19.7 percent of the community (see Table A1 and Figure 12). Differences in community composition among these beds in different pools are subtle. In summary, the mussel bed in Pool 10 has a slightly less even distribution, or lower species diversity, than do the beds in lower pools.

The presence of *D. polymorpha* was notable only at the bed in Pool 14. Overall density of this species at the nearshore and farshore sites in Pool 14 was 8.2 individuals/square meter. Zebra mussel densities at all other beds were less than five individuals/square meter. Differences are minor; at the bed in Pool 14, the presence of *D. polymorpha* adds a single organism to the group that comprises greater than 4 percent of the community (see Figure 14).

Species area curves

The relationship between the cumulative number of individuals versus the cumulative number of species provides a measure of the rarity of species. Species-area curves were developed for quantitative samples collected at nearshore and farshore locations at all beds surveyed in 1994 (Figures 17-21). *Dreissena polymorpha* was not included, and nearshore and farshore locations were kept separate. When the curve shows a long plateau at the end, it can be assumed that all, or nearly all, of the species present have been collected. It must be remembered that the number of species found is always related to the number of individuals collected.

For beds in Pools 17, 14, 12, and 10, the graphical relationship between these parameters depict a situation in which most or all species present have probably been found after several hundred individuals were collected. The bed at Pool 24 exhibited comparatively low species richness. Probably more species were present at this site, but the comparatively few number of individuals collected (less than 250) made it difficult to find very uncommon species. Had 1,000 individuals been collected, it would probably be possible to find species that comprised approximately 0.1 percent of the community.

Species richness and species diversity

The total number of species collected at each mussel bed was 16 at RM 299.6, 18 at RM 450.4, and 20 at the three most upriver mussel beds (Appendix A and Figure 22). Total species collected is positively related to the number of individuals obtained. However, some species present in the upper river (*L. higginsi* and *Quadrula metanevra*) are not found at RM 299.6, which is one reason richness at this site is typically less than at sites farther upriver.

Species diversity (H′), which depends on both the number of species present and the evenness of their distribution in a community, was lowest at RM 635.2 (Figure 23). This is the result of the extreme dominance of *A. p. plicata*, which comprised nearly half of the community at the bed in Pool 10. Species diversity was also comparatively low at RM 299.6, which was strongly dominated by *T. truncata*, which comprised 36.2 percent of the community (Table A1, Appendix A). At RM 450.4, 504.8, and 571.5, the more abundant species were more evenly distributed (there was not a single strong dominant), so species diversity indices tended to be slightly higher.

Evidence of recent recruitment

The percentage of individual mussels and species less than 30-mm total SL was used as an index of recent recruitment (successful recent reproduction). Individuals less than 30-mm total SL are probably 1 to 2 years old. For species that are small and short-lived (*Truncilla* spp.), this size range could include adults. However, presence of live species of *Truncilla* still provides evidence of recent recruitment. The percentage of individuals less than 30-mm total SL was approximately 30 at all sites except in Pool 10 at RM 635.2 where it was only 12.8 (Table A9 and Figure 24). The percentage of species that were evidence of recent recruitment ranged from a low of 43.75 at RM 299.6 to 60.0 at RM 571.5. Although numbers are variable among sites, it should be recognized that approximately 50 percent of the species present, many of which represented less than 1 percent of the community, had recent recruits.

Trends in percent abundance with respect to RM

Based on results of quantitative sampling, the relationship between percent abundance and RM was investigated for common to abundant species (Figures 25-27). Three species, *Fusconaia flava, Lampsilis cardium,* and *A. p. plicata,* showed a trend of increased abundance moving upriver (Figure 25). *Amblema p. plicata* exhibited the clearest relationship. This species is more common in the upper river where habitats are more lacustrine and sediments are more fine-grained than in the lower pools. *Fusconaia flava* and *L. cardium* exhibit the same trend as *A. p. plicata,* although the relationship is not quite so clear.

Three species, *O. reflexa, Obovaria olivaria,* and *E. lineolata,* exhibit the reverse trend, becoming less common moving upriver (Figure 26). *Obovaria olivaria* is much more common at farshore rather than nearshore subsites; the other two species do not exhibit any specific trend with respect to distance from shore. Four species, *Megalonaias nervosa, L. fragilis, Truncilla donaciformis,* and *T. truncata,* exhibit no specific trend with respect to RM or distance to shore (Figure 27).

Density

Mean density (numbers/square meter) for native mussels and *D. polymorpha* was determined by subsite and site for each mussel bed surveyed in 1994 (Tables 5 and 6, Figure 28). Overall density of native mussels ranged from a low of 16.2 ± 1.90 (Standard Error, SE) at RM 299.6 to a high of 60.2 ± 2.48 at RM 504.8 (Table 5). There were no significant intersite density differences (differences between nearshore and farshore sites) for mussel beds at RMs 299.6, 504.8, and 635.2. At RM 405.4, the nearshore site was significantly more dense; at RM 571.5, the farshore site was significantly more dense than the nearshore site.

Mean density of *D. polymorpha* ranged from 0.27 ± 0.13 at RM 299.6 to 8.2 ± 1.29 at RM 504.8, which was significantly higher than at the other mussel beds (Table 6). Significant nearshore-farshore density differences for this species existed at RM 405.4 only.

Evidence of recent mortality

The number of mussels in quantitative samples that were obviously freshly dead was recorded (Table 7). Freshly dead organisms had at least some intact tissue, gaped valves, and did not respond to stimuli. This year, as in previous years, the number was low. Only one fresh dead mussel was collected during the entire 1994 survey. This individual was collected at subsite 3 at the nearshore site at RM 299.6 (Table 7).

Presence of *L. higginsi*

The numbers and percent abundance of *L. higginsi* collected during the 1994 survey have been separately recorded (Table 8). No *L. higginsi* have ever been taken at RM 299.6. This species was collected using qualitative methods at the bed in Pool 17 on two occasions, once in 1988 and again in 1994. At RM 504.8, *L. higginsi* represented 0.76 and 0.44 percent of the qualitative and quantitative collection, respectively. *Lampsilis higginsi* was not found at RM 571.5 during this year, but it was collected using quantitative methods in Pool 10. Year-to-year variations are not unexpected with this uncommon species.

Demographic Analysis of Dominant Populations

Populations sampled in sufficient numbers to inspect size demography did not exhibit important differences at nearshore versus farshore sites. Thus, demography was analyzed using the combined results of nearshore and farshore sampling. A description of the demography of dominant populations in each pool is provided below.

Pool 24

Five species were collected in sufficient numbers for demographic analyses in Pool 24 (Figure 29). These included small-to-moderate-sized mussels of species that grow to large adult size (*A. p. plicata* and *L. fragilis*) and all size classes of species that grow to moderate (*E. lineolata*) or moderately small adult size (*O. reflexa* and *T. truncata*).

Amblema plicata plicata. Only 22 individuals of *A. p. plicata* were obtained from quantitative samples taken in Pool 24. A single cohort

comprised virtually all of this population, with 21 individuals ranging only from 44 to 70 mm long. The average length of these individuals was 58 mm. A single mussel was obtained that was not of this cohort and measured 95 mm long.

Ellipsaria lineolata. Twenty-nine *E. lineolata* were obtained in quantitative samples. A cohort ranging in length from 26 to 38 mm comprised 55 percent of the sample; this dominant cohort had an average length of 32 mm. These small mussels probably represented 1993 recruitment. Remaining individuals in the population sample ranged from 46 to 70 mm long.

Leptodea fragilis. Twenty-seven *L. fragilis* were collected. A cohort with modal length of 64 to 72 mm dominated the sample. Several smaller individuals were obtained, ranging in length down to 7 mm. The largest individual collected measured 85 mm long, although this species grows to well over 100 mm long at its maximum adult size.

Obliquaria reflexa. Two small cohorts were clearly discerned. The smallest ranged from 14 to 24 mm and probably represented 1993 recruitment. The next larger cohort ranged from 26 to 36 mm and probably represented 1992 recruitment. Mussels greater than 36 mm long probably included individuals of 3-year classes; however, the sample was not sufficiently large to support detailed analysis of the larger cohorts.

Truncilla truncata. A total of 89 *T. truncata* were collected. This population appeared to consist of two cohorts. The smallest cohort, probably representing 1993 recruitment, ranged from 18 to 32 mm long and had an average length of 24 mm. This cohort comprised 70 percent of the population. Mussels ranging from 28 to 52 mm long probably consist of two cohorts. The 1992 year class, with mean length of 36 mm, probably dwarfs the 1991 year class, with modal length of perhaps 43 mm.

Pool 17

Eight species were collected in sufficient numbers to support demographic analysis of population samples (Figure 30). These included three species that grow to large adult size (*A. p. plicata, M. nervosa,* and *L. fragilis*), three species that grow to moderate size (*E. lineolata, Q. pustulosa,* and *Q. metanevra*), and the moderately small-size species *O. reflexa* and *T. truncata.*

Amblema plicata plicata. The population of *A. p. plicata* in this pool was much more abundant and complex in size structure than in Pool 24. Individuals ranged from 12 to 100 mm long and represented many year classes. Prominent cohorts appeared to be centered at 15 (1993 recruits), 39, 53, 63, 72, and 81 mm. Cohorts of somewhat lesser abundance were "hidden" between these peaks. Mussel abundance decreased greatly for the 90- to 100-mm-length range, probably representing the size at which mortality removes older mussels from this population.

Ellipsaria lineolata. This population was clearly comprised of multiple cohorts and represented the full-size range of this species. Recent recruitment has been strong. Individuals ranging from 18 to 36 mm long comprised approximately 35 percent of the population and probably reflect 1992 and 1993 recruitment. Mussels ranging from 36 to 82 mm clearly included multiple cohorts that largely overlapped in length.

Leptodea fragilis. The relatively small sample included moderately small to moderately large individuals. Mussels ranged from 44 to 188 mm long. Most individuals were between 52 and 82 mm long.

Obliquaria reflexa. A recent recruitment cohort (probably 1993 recruits) was clearly evident. This cohort ranged in length from 12 to 24 mm and had an average length of 18 mm. The remainder of the population ranged from 26 to 52 mm long and probably included multiple but indistinguishable cohorts.

Quadrula pustulosa. This sample represented the entire size range of this species. The smallest individual collected was 12 mm long, and the longest was 72 mm. Recruits from 1993 appeared to have an average length of 17 mm. Mussels ranging upward to 82 mm undoubtedly include many cohorts. Peak abundances were evident at 32 to 38 mm, at 42 to 48 mm, and 50 to 64 mm. Although these first two peaks probably represent single-year classes, the third almost certainly includes at least 2-year classes.

Megalonaias nervosa. Despite a small sample size (n = 23), important information was yielded on the size structure of this population. The two mussels less than 60 mm long indicate recent recruitment, as this is a relatively elongate species that can grow to very large size (>175 mm). The cluster of individuals from 98 to 134 mm indicates that these size classes are the most abundant in the population.

Quadrula metanevra. A single mussel less than 30 mm long was included among the 27 individuals collected. This small mussel in a small sample suggests moderate recent recruitment. The highest abundance was of mussels 54 to 72 mm long.

Truncilla truncata. The Pool 17 population was similar to the Pool 24 population. The 1993-year class, ranging from 14 to 26 mm long and having average length of 21 mm, was the most abundant component of the population. The 1992-year class ranged approximately from 22 to 42 mm and had average length of 31 mm. The 1991-year class was much less abundant and therefore less evident. This oldest cohort probably ranged from 36 to 52 mm and appeared to have an average length of 43 mm.

Pool 14

Seven species were collected in sufficient abundance to warrant demographic analysis (Figure 31). Larger size species included *A. p. plicata*,

Q. quadrula, and *L. fragilis*. Moderately large species included *E. lineolata* and *Q. pustulosa*. Relatively small species included *O. reflexa* and *T. truncata*.

Amblema plicata plicata. This population consisted of consecutive, multiple-year classes. Although substantial recruitment appears to have occurred in all years, very recent recruitment (i.e., 1993 and 1992) has been less strong than recruitment just a few years earlier (i.e., 1991, 1990, and 1989). Small mussels (10 to 35 mm long) are less abundant than moderate-sized mussels (mussels 35 to 55 mm long). Despite a relatively large sample (n = 162), cohort structure was not clear, even among these small-to-moderate-sized mussels. The higher relative abundance of an older year class in an adjacent pair makes it difficult to discern the younger cohort, which may be hidden in the "lower tail" of the length-frequency distribution of the older cohort.

Ellipsaria lineolata. This population was almost identical to that of the same species in Pool 17, with the increasingly larger cohorts being of diminished abundance. This population consisted of multiple-year classes. The youngest cohort was the most distinct. This cohort, probably representing 1993 recruitment, ranged in length from 22 to 32 mm and had an average length of 27 mm.

Quadrula pustulosa. This population appeared to consist of 7-year classes. The most recent, probably 1993, had an average length of 14 mm. The 1992 cohort appeared to have an average length of 23 mm and was approximately three times more abundant than the 1993 cohort. The 1991 cohort, with average length of 32 mm, was of intermediate abundance. A cohort of very low abundance, and thus not evident in the length-frequency histogram, probably had average length of approximately 40 mm. The next larger cohort, probably 1989 recruits, had average length of 47 mm. In turn, a cohort was clearly evident with an average length of 53 mm. This cohort presumably represented 1988 recruitment. Finally, a cohort was evident with an average length of 57 mm (presumably 1987 recruits). This interpretation suggests annual growth of 9 mm from age 1 to 2 years, 9 mm from age 2 to 3 years, 8 mm from age 3 to 4 years, 7 mm from age 4 to 5 years, 6 mm from age 5 to 6 years, and 4 mm from age 6 to 7 years.

Quadrula quadrula. Moderately strong and repeated annual recruitment was suggested by the presence of mussels ranging from 15 to 45 mm. The paucity of mussels from 45 to 52.5 mm could indicate a year of very weak recruitment of this species. The majority of mussels in the population ranged from 52.5 to 85 mm in length.

Obliquaria reflexa. Cohorts centered at 27 and 42 mm dominated this population. A relatively minor cohort, centered at 33 mm was evident in between the two dominant cohorts. In addition, a minor cohort of mussels with average length of 49 mm was evident. The major cohort at 27 mm probably represents 1992 recruitment; 1993 recruits, likely to be less than 20 mm

long, were apparently present in very low abundance. Thus, the 1993-year class was hidden within the "lower tail" of the length-frequency distribution of 1992 recruits.

Truncilla truncata. The smallest cohort, probably representing 1993 recruitment, had an average length of 17 mm. A cohort was possibly present with an average length of 25 mm, although this cohort overlapped with the smallest cohort sufficiently to be less than clear. Additional cohorts were evident that had average lengths of 32 and 42 mm.

Leptodea fragilis. This population was dominated by mussels of intermediate size. This elongate species can grow to well over 100 mm long, although such large mussels were not present in this population. The mussels less than 40 mm long indicated substantial recent recruitment.

Pool 12

Four species were obtained from quantitative samples in sufficient numbers to warrant demographic analysis (Figure 32). In order of their maximum adult size, these species were as follows: *A. p. plicata, L. fragilis, O. reflexa, and T. truncata.*

Amblema plicata plicata. In general, size structure was very similar to that observed in Pool 17. The population consisted of essentially all year classes. Mussels less than 20 mm long, 56 to 60 mm long, and greater than 90 mm long were of reduced abundance in a population that otherwise had fairly equal representation of other size classes.

Leptodea fragilis. This population had striking evidence of very recent recruitment. Mussels less than 22 mm long comprised 31 percent of the population. As in Pool 14, mussels of moderate size were abundant, but no mussel larger than 100 mm was collected.

Obliquaria reflexa. This population was comprised of three or four cohorts. Mussels centered at 25 mm probably represented 1992 recruitment. The minor peak at 35 mm may have represented 1991 recruitment, and the major peak at 41 mm probably represented 1990 recruitment. The very minor peak at 51 mm was consistent with the expected size of mussels recruited in 1989.

Truncilla truncata. Cohort structure was difficult to discern in this population. A very abundant cohort, with average length of 20 mm, dominated. It is likely that this cohort represented the 1993 year class. Mussels of intermediate size 24 to 40 mm were also abundant and represented a mix of 2- or 3-year classes. The largest individual sampled was 57 mm long.

Pool 10

Four species were collected in sufficient numbers for demographic analysis: *A. p. plicata, L. fragilis, T. truncata,* and *O. reflexa* (Figure 33).

Amblema plicata plicata. This population was more similar to that in Pool 14 than to those in either Pools 17 or 12. Ignoring detailed aspects of the size-frequency distribution, the abundance of this mussel in Pool 10 increased from 10 to 40 mm, remained relatively stable from 40 to 60 mm, and then increased greatly from 60 to 90 mm. As size increased above 90 mm, the decline in abundance likely reflects high mortality of the largest and oldest mussels in the population (whether by natural causes or because of harvesting). The general increasing abundance of mussels from 10 to 40 mm probably reflects greater recruitment strength in 1991 than in 1992 or 1993. The high abundance of mussels from 60 to 90 mm probably reflects the combined effects of slowed growth and low mortality such that cohorts become blended together in these moderately large-size classes.

Leptodea fragilis. Moderate-sized (40 to 80 mm) individuals dominated. Very small mussels were present but not abundant. Only a few individuals exceeded 100 mm.

Truncilla truncata. This population was strikingly different from the *T. truncata* populations in all other pools. Individuals greater than 30 mm long heavily dominated the Pool 10 population, but individuals less than 30 mm long were much more abundant in the other pools. Although some 1993 recruits (10 to 22 mm) were present in Pool 10, this year class was not abundant in the uppermost pool.

Obliquaria reflexa. This population sample was too small to warrant detailed analysis. However, moderately small *O. reflexa* (22 to 32 mm) represented the most abundant cohort in the population. This cohort probably represented 1992 recruitment.

Interpool Comparisons of Size Demography

Amblema plicata plicata

The most abundant mussel in the UMR, *A. p. plicata*, showed interpool variation in demography (Figure 34). The most notable difference was between Pool 24 and all other pools. This population in Pool 24 was heavily dominated by a single-year class, whereas populations in all other pools were very complex in size and age structure. Finer grained differences were noted among populations in Pools 17 through 10. Both the Pool 17 and Pool 12 populations showed more equitable abundance of moderately young year classes than did the Pool 14 and Pool 10 populations.

High mortality of mussels greater than 90 mm long was indicated in all four pools with populations with complex size structure. A marked decline in abundance of mussels greater than 90 mm long was quantified by comparing the ratio of the number of 80.0- to 89.9-mm-long mussels with 90.0- to 99.9-mm-long mussels in each pool. These ratios equaled 2.9, 1.9, 14.0, and 4.3 in Pools 17, 14, 12, and 10, respectively.

The percent of mussels less than 30 mm provided a measure of recent recruitment strength. Thus estimated, relative abundance of recent *A. plicata* recruits equaled 0, 12, 10, 16, and 8 percent in Pools 24, 17, 14, 12, and 10, respectively. The most recent year class included in quantitative samples in Pools 17 through 10 appeared to range in length from 10 to 20 mm and had an average length of approximately 15 mm. Based on previous estimates of early growth rate (see Figure 24, Miller and Payne 1994), this cohort probably represents 1993 recruitment.

Leptodea fragilis

The Pool 12 population of this species stood out from all others because of the high abundance of individuals less than 22 mm (Figure 35). Otherwise, this population was similar to the others. Moderate-sized mussels (60 to 80 mm) were abundant in all populations. Few very large (>100 mm) *L. fragilis* were obtained in any of the pools.

Ellipsaria lineolata

Populations in Pools 24, 17, and 14 were all characterized by decreasing abundance of larger, older cohorts (Figure 36). This pattern also held for Pool 12 based on the few mussels collected at that site. *Ellipsaria lineolata* becomes less abundant with increasing distance upriver in the UMR; thus, population samples were too small to warrant demographic analysis in Pools 12 and 10.

Obliquaria reflexa

Populations in all pools consisted of three to five cohorts (Figure 37). Pools 10, 12, and 14 populations had few 1993 recruits. The Pool 12 population also did not include many 1992 recruits, although these were very abundant in both Pools 10 and 14.

Truncilla truncata

This species showed a very interesting pattern of change with distance upriver (Figure 38). In Pool 24, the population was heavily dominated by mussels less than 30 mm long. In Pool 10, the population was heavily

dominated by mussels greater than 30 mm long. Pools 12, 14, and 17 represented a gradual transition between these extremes.

Assessment of Demography with Composite Samples

Populations with complex age and size structure, typical of most unionids, must be sampled extensively if individual cohorts are to be identified in length-frequency histograms. It is ideal if at least 20 to 30 individuals are obtained of each cohort. Even then, disproportionate abundances of closely adjacent cohorts as well as a "blending" effect of slowed growth with increased size usually does not allow all cohorts to be identified. The following paragraphs describe composite representation of UMR populations of several species (Figure 39). An underlying assumption, when interpreting size-to-age relationships, is that mussel growth rates per species are very similar among pools.

Amblema plicata plicata

The two youngest cohorts were clearly discerned. The 1993-year class ranged from 10 to 20 mm and had an average length of 15 mm. The 1992-year class ranged from 18 to 30 mm and had an average length of 25 mm. The 1991-year class appeared to have an average length of 32 mm. However, this cohort was overwhelmed in abundance by the next larger cohort. The 1990 cohort appeared to have an average length of 38 mm. All larger and older cohorts were difficult to discern. The interpretation above suggests the following annual increments of growth:

10 mm	second to third growth season
7 mm	third to fourth growth season
6 mm	fourth to fifth growth season

These estimates fall within the anticipated annual increment of approximately 9 mm that has been estimated for *A. p. plicata* in the UMR (Miller and Payne 1994).

A few observations concerning large mussels were possible in addition to these estimates of early growth rate. First, the composite plot of all *A. p. plicata* collected from quantitative samples in the UMR in 1994 clearly indicates that mortality takes a heavy toll on mussels approximately 90 mm long or greater. In addition, hardly any individuals were obtained with length greater than 100 mm.

Leptodea fragilis

The composite sample of this species in the UMR clearly showed that few large individuals occurred. Most mussels were less than 75 mm long—a relatively small size in this elongate species that grows to well over 100 mm. The population is either one in which mortality takes mussels before they reach average adult size, or this population is in transition toward a greater abundance of large mussels in a few more years.

Megalonaias nervosa

A composite sample was the only means to support detailed inspection of demography of this important commercial species, because only a few individuals were collected in each pool. Mussels ranging from 30 to 90 mm long clearly indicated steady, moderately strong recruitment to the population. Mussels greater than 135 mm were not abundant, even though this species can grow to much greater lengths.

Quadrula pustulosa

Cohort structure was reasonably distinct in this composite sample. The youngest recruits (1993-year class) ranged from 12 to 20 mm and had an average length of 15 mm. The 1992-year class was very abundant and had an average length of 23 mm. The next major peak at 33 mm probably corresponded to the average length of 1991 recruits. The next major peak at 47 mm probably corresponded to the average length of 1989 recruits. Less abundant 1990 recruits were probably obscured in the overlapping tails of the length-frequency histograms of these two major cohorts. The major peak at 53 mm probably represents the average length of 1988 recruits. Recruits from earlier years are likely to occur from 57 to 71 mm.

Based on the above interpretation, a model of annual-growth increment during early to middle life of *Q. pustulosa* is as follows:

8 mm	second to third growth season
10 mm	third to fourth growth season
17 mm	fourth to sixth growth season
6 mm	sixth to seventh growth season

Obliquaria reflexa

Cohort structure was reasonably evident in the composite length-frequency histogram of this species of intermediate size and lifespan. The peak centered at 19 mm presumably represented the average length of 1993 recruits. Recruitment during 1992 appeared to have been somewhat stronger than in 1993. The 1992-year class average length was represented by the peak

centered at 27 mm. The next obvious peak was at 42 mm and probably corresponded to the average length of 1990 recruits. The "peak" at 35 mm probably represented the average length of 1991 recruits hidden between major recruitment cohorts of 1992 and 1990. The last obvious peak, at 49 mm, probably represented the average length of 1989 recruits. Older mussels probably were included among those individuals greater than 53 mm long.

Thus interpreted, the composite length-frequency histogram suggests the following annual increments of growth:

8 mm	second to third growth season
8 mm	third to fourth growth season
7 mm	fourth to fifth growth season
7 mm	fifth to sixth growth season

The sixth season of growth appeared to have been the last for most individuals in this population.

4 Discussion

The purpose of this monitoring program was to document important biotic attributes of prominent mussel beds in the UMR. Six attributes indicative of the overall health of a mussel bed were identified to evaluate change. In the following section, the six attributes of the mussel fauna at these beds will be examined using data collected in 1994.

Decrease in Density of Five Common-to-Abundant Species

As described in this report, density of common-to-abundant species varied with respect to distance from shore and RM (Figures 25-27). *Amblema p. plicata* was most abundant in the upper river and least abundant in lower pools. Since this survey was initiated, this species has always been common to abundant in the UMR. Distribution of the two species of *Truncilla* appear unrelated to RM or distance to shore (Figure 27). However, year-to-year variations are much more likely with these species since they are comparatively short-lived.

Total mean density of the native mussels varies with respect to location and distance to shore (Table 5). Year-to-year variation is likely for several reasons. First, although most mussels live 10 or more years, short-lived species (*Truncilla* spp.) are more likely to show yearly fluctuations in density that affect total mean values. Second, beds are not sampled in exactly the same location each year; therefore, spatial variation within the bed could appear as temporal variation. Finally, both short- and long-lived species exhibit periods of recruitment and mortality that will affect overall mean density values.

Presence of *L. higginsi*

Lampsilis higginsi has never been found in Pool 24, is rarely taken in Pool 17, and is usually collected at beds in Pools 14, 12, and 10 (Table 8). During the 1994 survey, percent composition varied from 0.0 to a maximum of 1.72. It is not uncommon to collect several hundred mussels at a bed and not

find this species, although it typically comprises 0.5 percent or more of the community.

Live-to-Recently-Dead Ratios for Dominant Species

The number of fresh-dead mussels (those obviously dead but with tissue still attached to the shells) has been monitored since 1988. Other workers collecting in the late 1980s and early 1990s have reported considerable numbers of fresh dead mussels. During this entire study, few fresh dead mussels have been found (see Table 7).

Loss of More Than 25 Percent of Mussel Species

The number of species identified at a site is related to the number of individuals collected. Year-to-year variation in this parameter is partially the result of differences in the collecting effort. Close to 30 species have been found at mussel beds in Pool 10. During 1994, only 20 species were found at the study site in the main channel at RM 635.2 (Table A9). Additional uncommon species would probably be found with extra sampling effort.

Evidence of Recent Recruitment

The percentage of species and individuals less than 30 mm total SL that were identified in 1994 represent successful reproduction in 1994 or 1993. At the five mussel beds, 43 to 60 percent of the individuals were evidence of recent recruitment (Figure 24). These data can be contrasted with findings from mussel studies in the Big Sunflower River. In an intensive survey of that river, there was no evidence of recent recruitment for any species at any sites (Miller and Payne, In Preparation).

Demography

Early growth rate of *A. p. plicata* has now been estimated from three sources: measurements of length to consecutive annuli that consistently can be discerned on the outside of shells of small-to-moderate-sized mussels (Figure 24 in Miller and Payne 1994); detailed analysis of length-frequency histograms for very large samples in which closely adjacent consecutive year classes of recent recruits are distinguishable (Figure 23 in Miller and Payne 1994 and Figure 39 herein); and continued monitoring of the growth of a 1988 recruitment cohort that was essentially the only component of the Pool 24 population of the *A. p. plicata* population since studies began in 1988. In

1988, this cohort was so small that it probably passed through sieve screens; thus, not enough individuals were retained for demographic analysis. In July 1989, this cohort was first sampled and had an average length of 15 mm (Figure D1 Miller and Payne 1991). As reported herein (Figure 39), this cohort now has an average length of 58 mm. Thus, from age 1 to 6 years, this cohort has grown in average length by 43 mm (average of 8.6 mm per year).

This observed growth closely corresponds to the recent model of early growth that was based on shell annuli measurements. These were supported by detailed age-to-size relationships interpreted from the size-frequency histogram of an exceptionally large sample (Miller and Payne 1994). That model predicted a mean length of 15 mm at an age of 1 year and 52 mm at an age of 5 years (average of 9.3 mm per year). Observed growth of the 1988 cohort in Pool 24 from 1989 to 1994 indicates that growth averages 8.6 mm from age 1 to 6 years. Most investigations of mussel growth must be conducted without the benefit of direct evidence of an eye witness. Judgments are more confidently reached if the preponderance of indirect evidence from relatively independent lines of investigation leads to a common conclusion. In the case of the rate of early growth (i.e., ages 1 to 6 years) of *A. p. plicata* in the UMR, the conclusion that SL increases by an average of approximately 9 mm per year seems indisputable.

It is noteworthy that *Quadrula pustulosa* and *O. reflexa* showed annual length increases during early growth that are only slightly less than the 9-mm value suggested for *A. p. plicata*. All three species are thick-shelled and have morphometric similarities. None are especially elongated, and their width-to-length dimensions, ignoring shell sculpturing, are generally similar. The height-to-length ratio of both *Q. pustulosa* and *O. reflexa* is slightly greater than that of *A. p. plicata*. Thus, a given increment of length increase in the latter probably corresponds to slightly greater mass increase than the same increment of length increase in *Q. pustulosa* and *O. reflexa*. Increments of length increase indicated for both *Q. pustulosa* and *O. reflexa* both approximated 8 mm per year from the second to sixth or seventh season of growth. That this value is only slightly less than the 9-mm estimate for the slightly more elongate *A. p. plicata* suggests that these species increase their mass at similar annual rates during the first 7 or 8 years of life.

Continued monitoring of increasing size of the dominant cohort in the Pool 24 *A. p. plicata* population would allow quantification of size-to-age relationships in moderate-to-large mussels. Such quantification is especially difficult. Neither detailed analyses of shell annuli or of a length-frequency histogram based on a single year's sample provides sufficiently convincing evidence. Shell annuli become increasingly obscure and closely spaced as mussels grow old and large. Because large, old mussels increase in length considerably more slowly than small, round mussels, even exceptionally large samples do not allow closely spaced and largely overlapped consecutive year classes to be discerned in length-frequency histograms. The Pool 24 population, because it is heavily dominated by a single-year class, offers a special

opportunity for relatively direct observations of life-span growth of *A. p. plicata*—the most abundant and commercially important mussel in the UMR.

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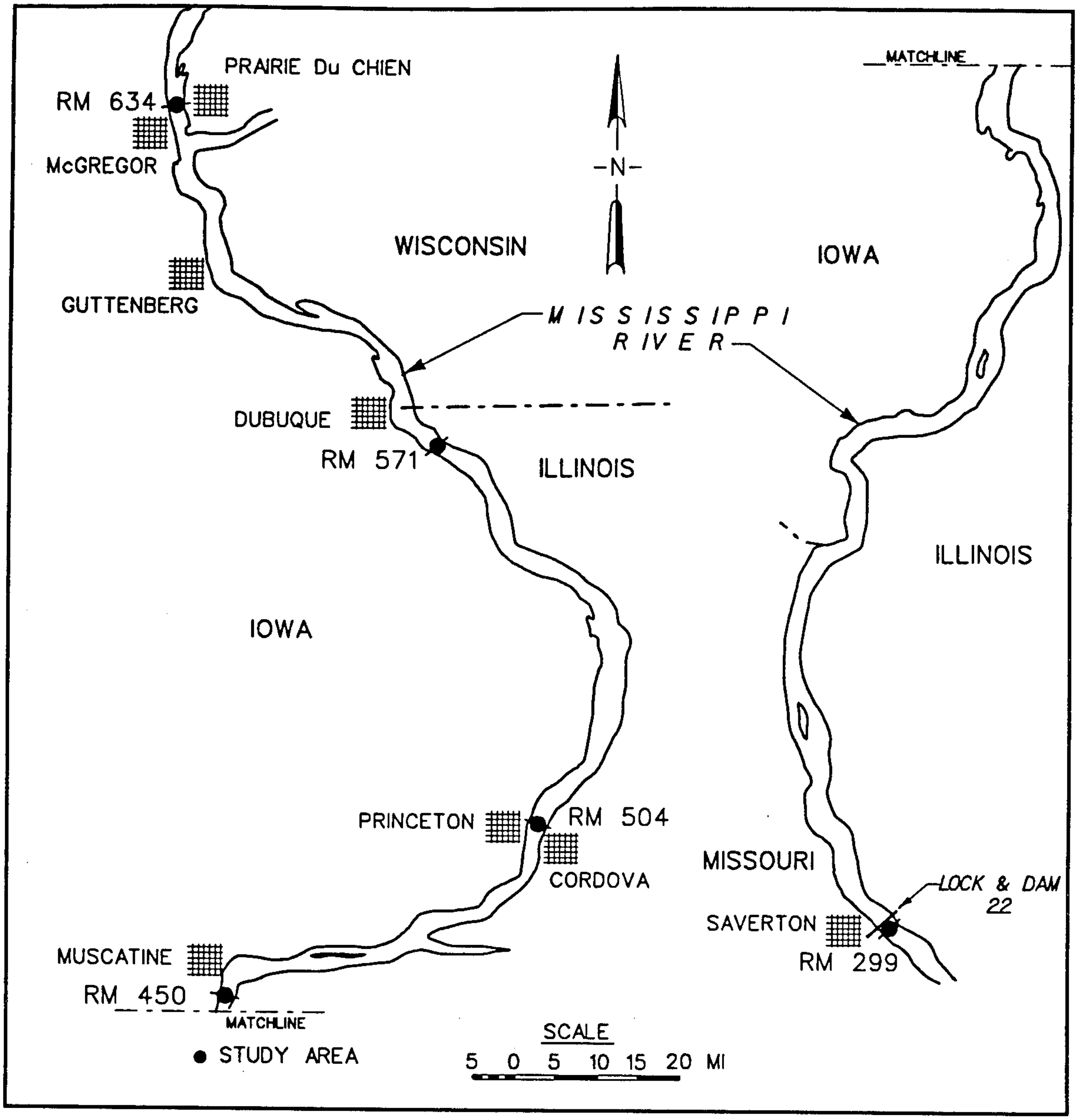

Figure 1. Location of five mussel beds chosen for detailed study in UMR, 1989-94

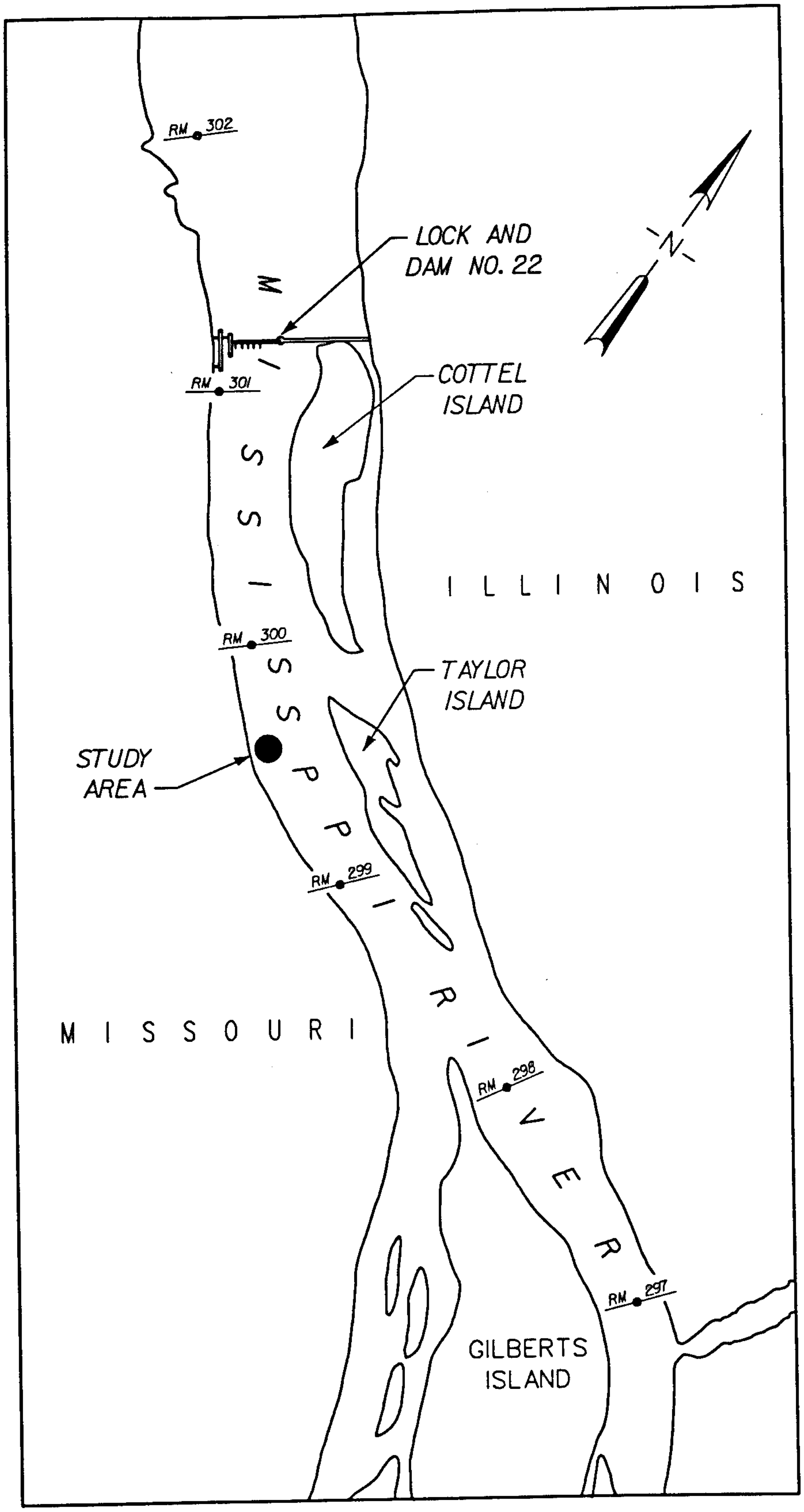

Figure 2. Location of mussel bed in Pool 24, UMR

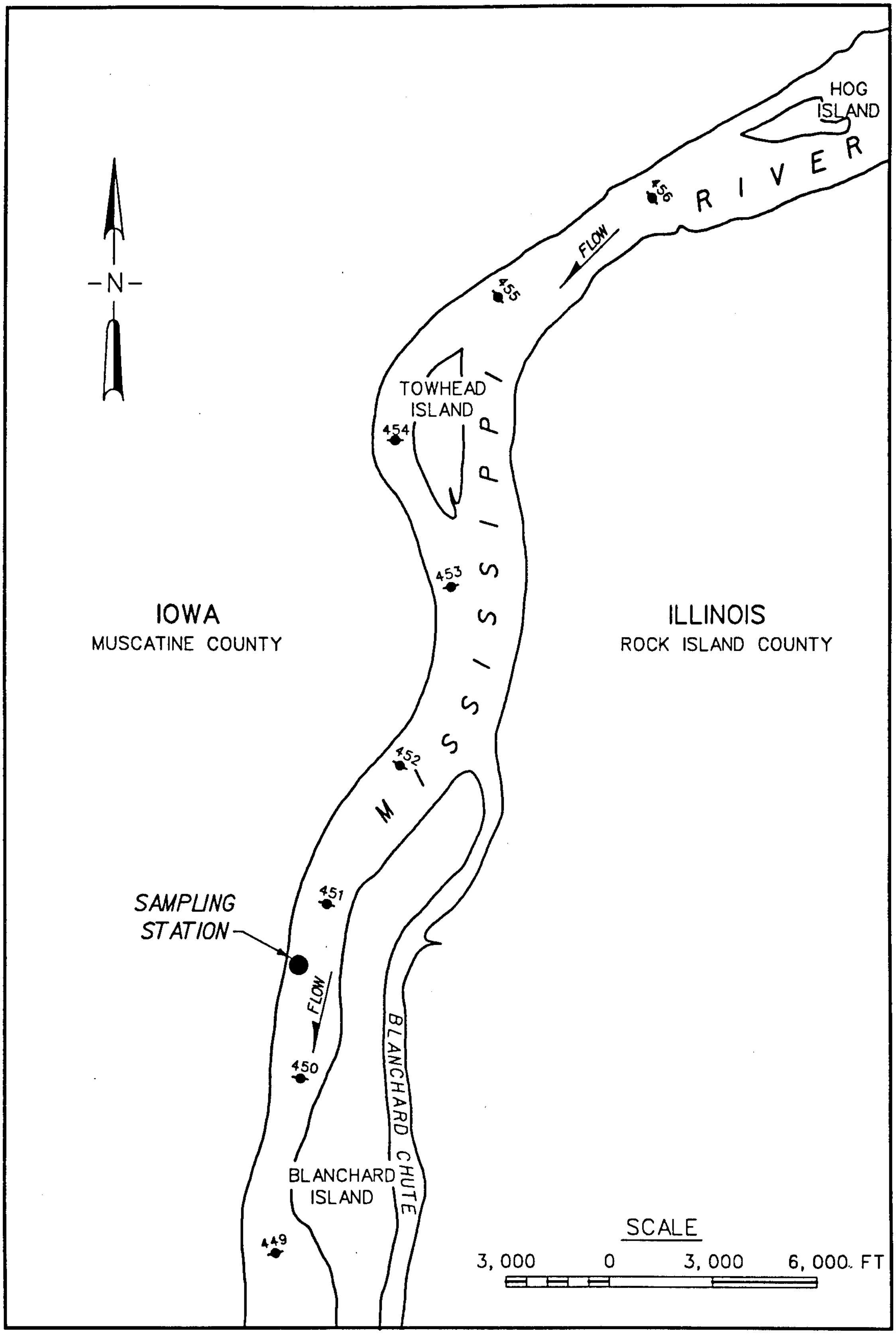

Figure 3. Location of mussel bed in Pool 17, UMR

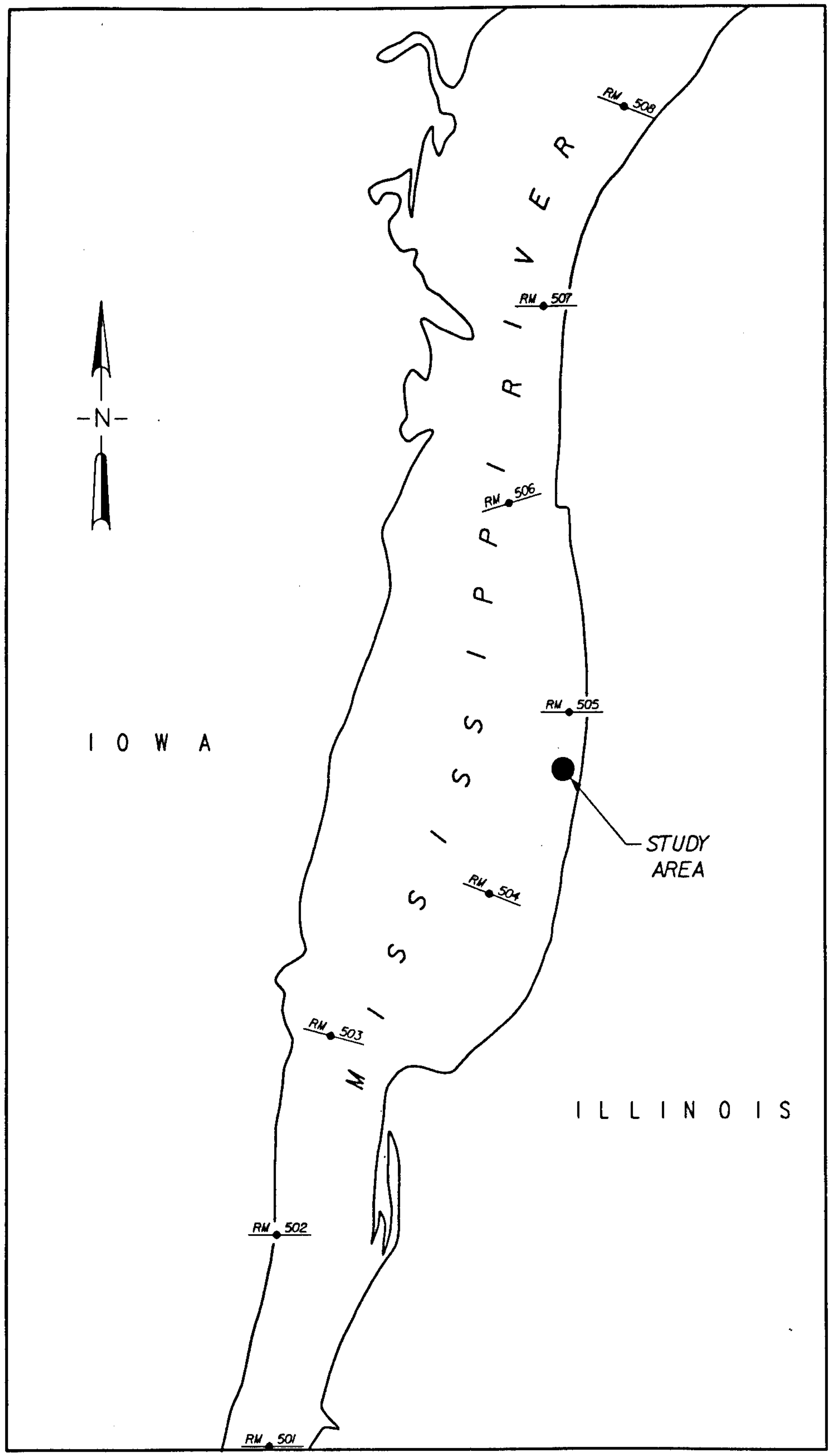

Figure 4. Location of mussel bed in Pool 14, UMR

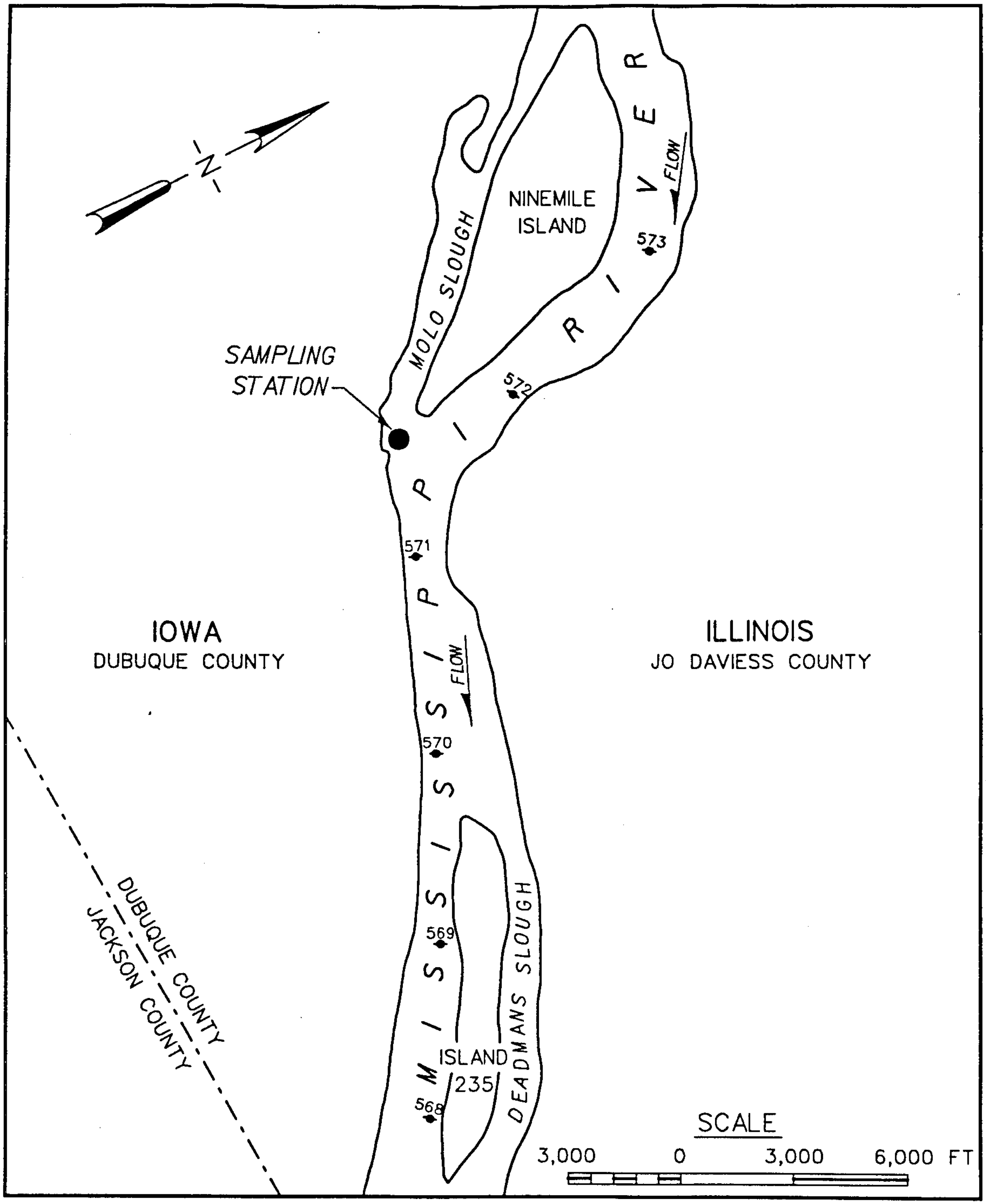

Figure 5. Location of mussel bed in Pool 12, UMR

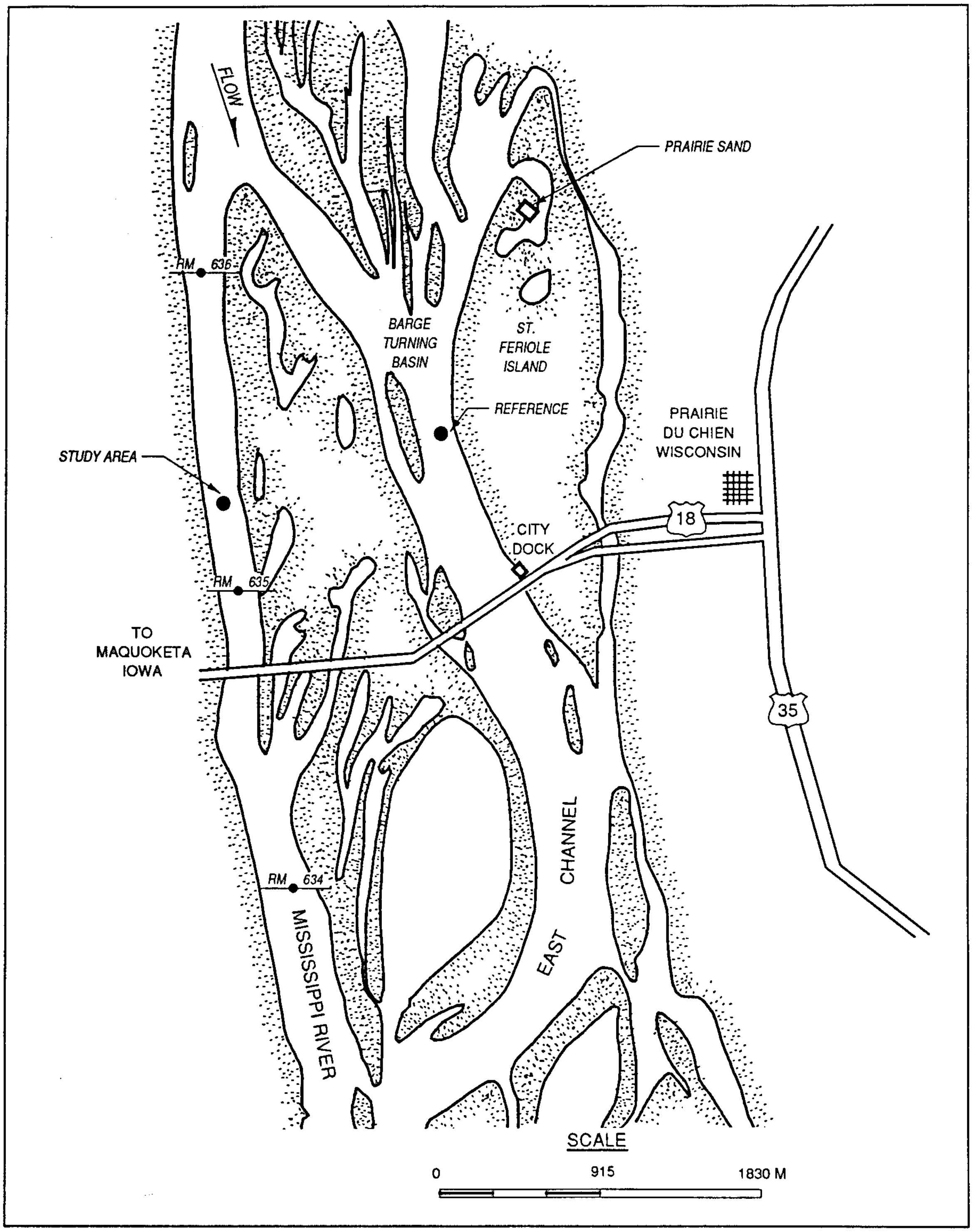

Figure 6. Location of mussel bed in Pool 10, UMR

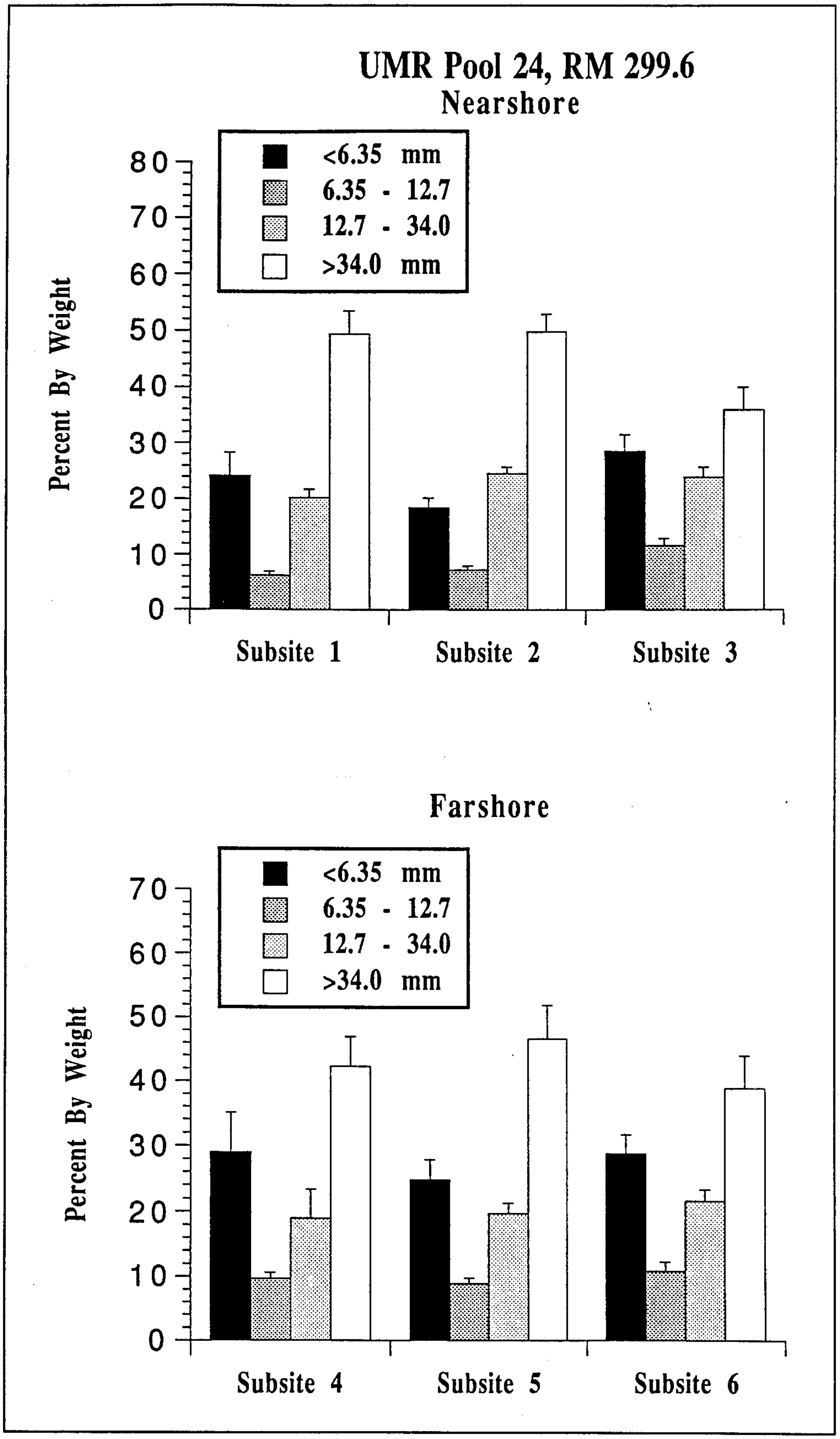

Figure 7. Sediment characteristics at a nearshore and farshore site at a mussel bed in Pool 24, UMR, 1994

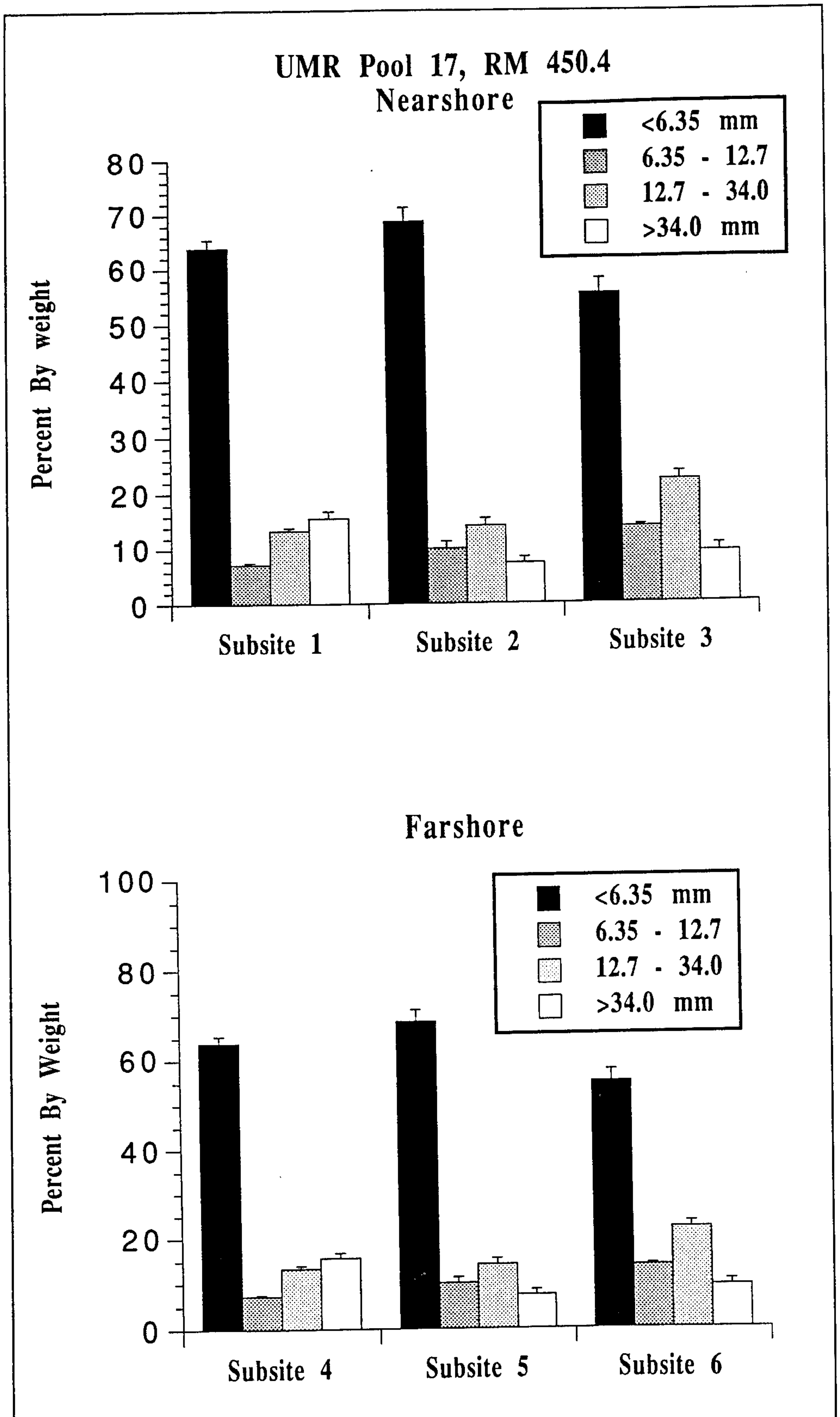

Figure 8. Sediment characteristics at a nearshore and farshore site at a mussel bed in Pool 17, UMR, 1994

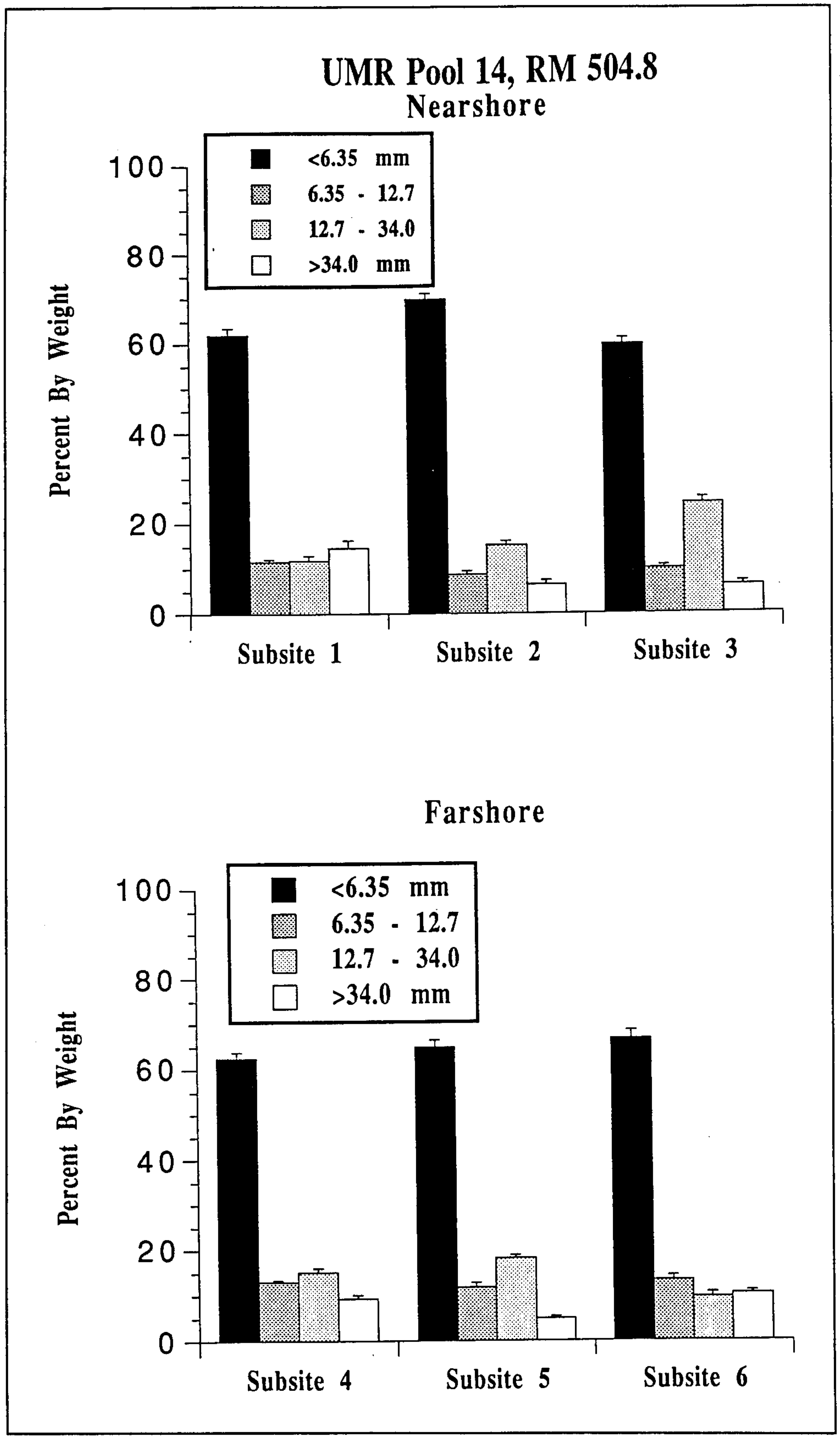

Figure 9. Sediment characteristics at a nearshore and farshore site at a mussel bed in Pool 14, UMR, 1994

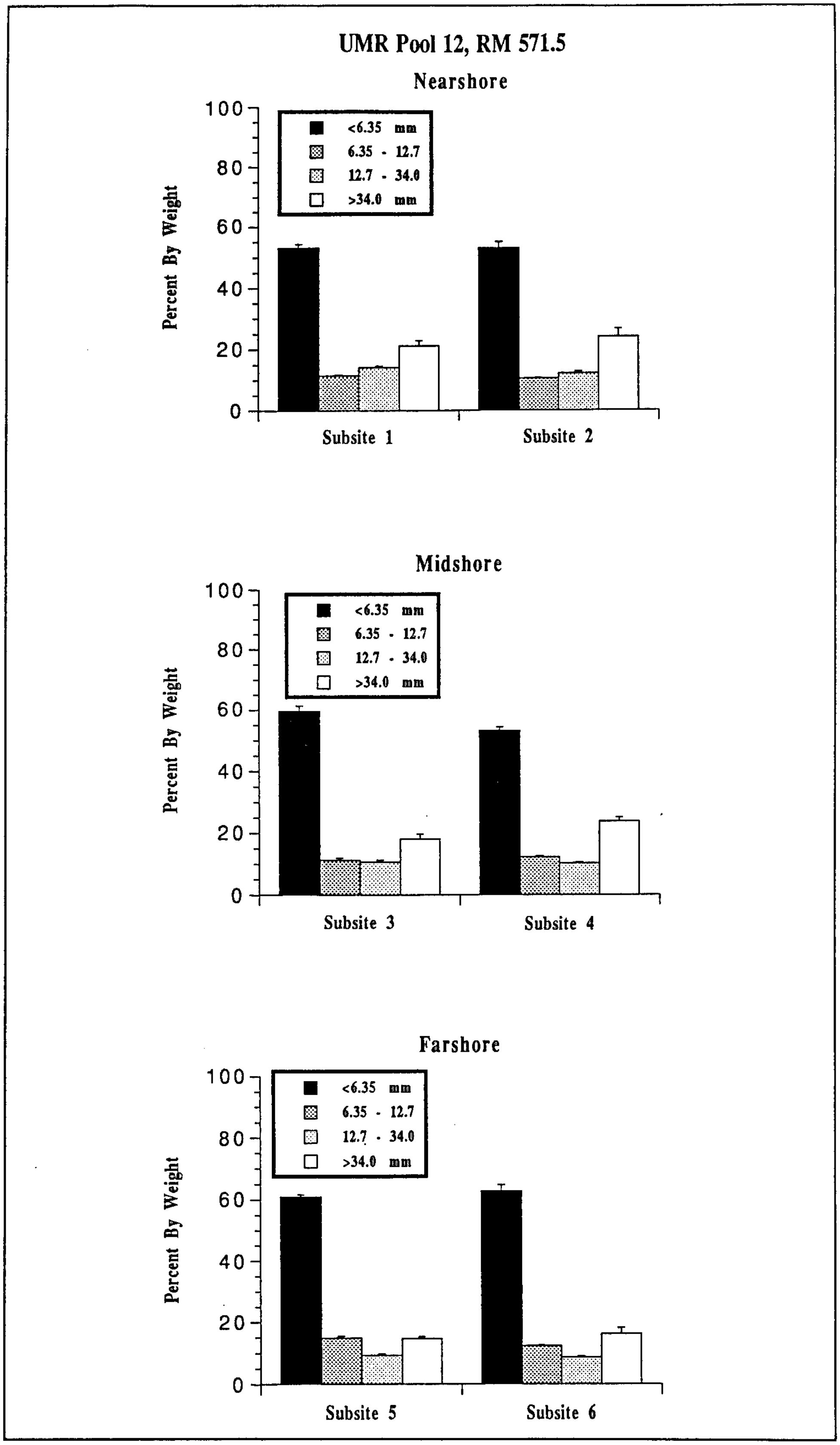

Figure 10. Sediment characteristics at a nearshore, midshore, and farshore site at a mussel bed in Pool 12, UMR, 1994

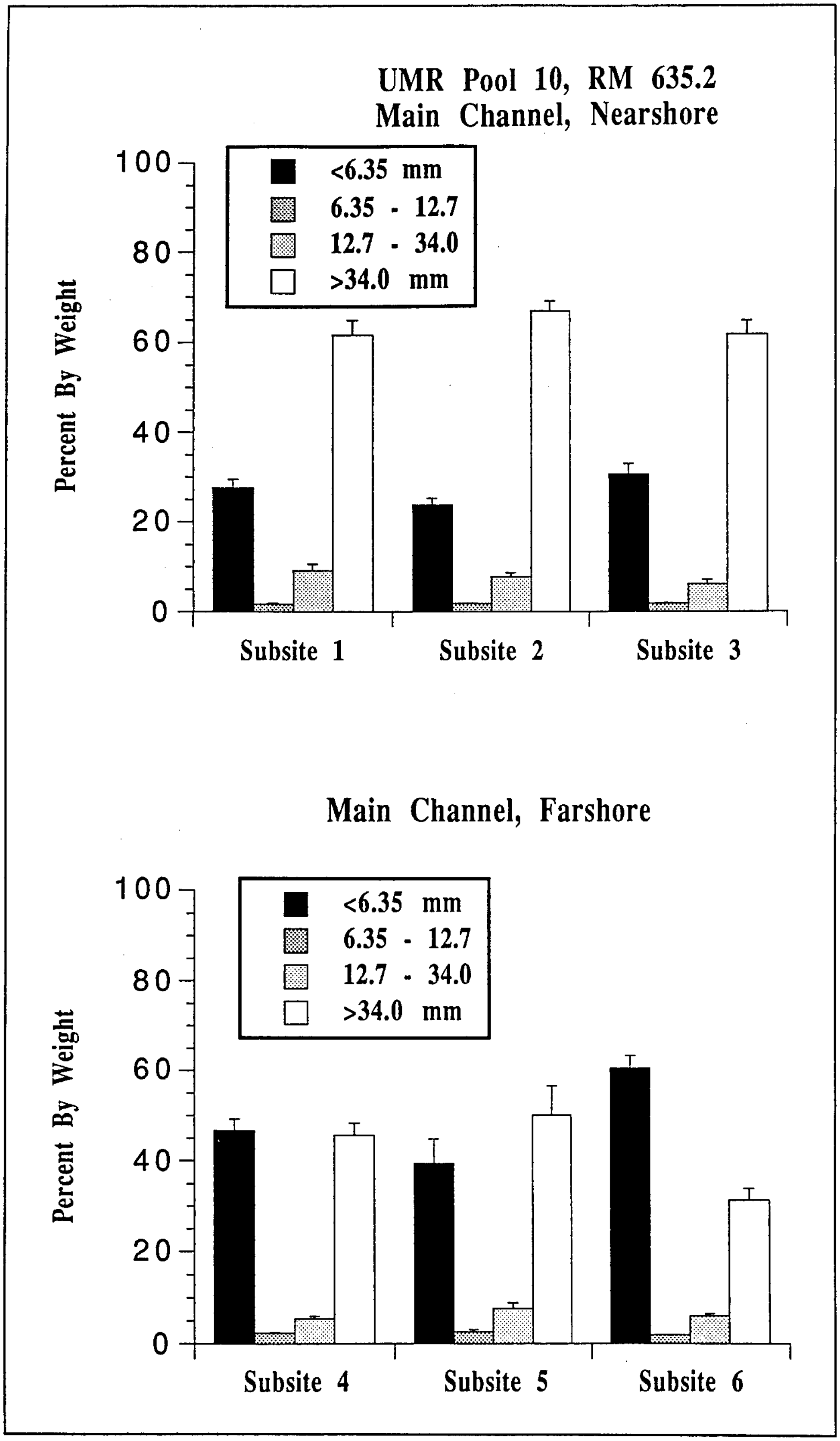

Figure 11. Sediment characteristics at a nearshore and farshore site at a mussel bed in Pool 10, UMR, 1994

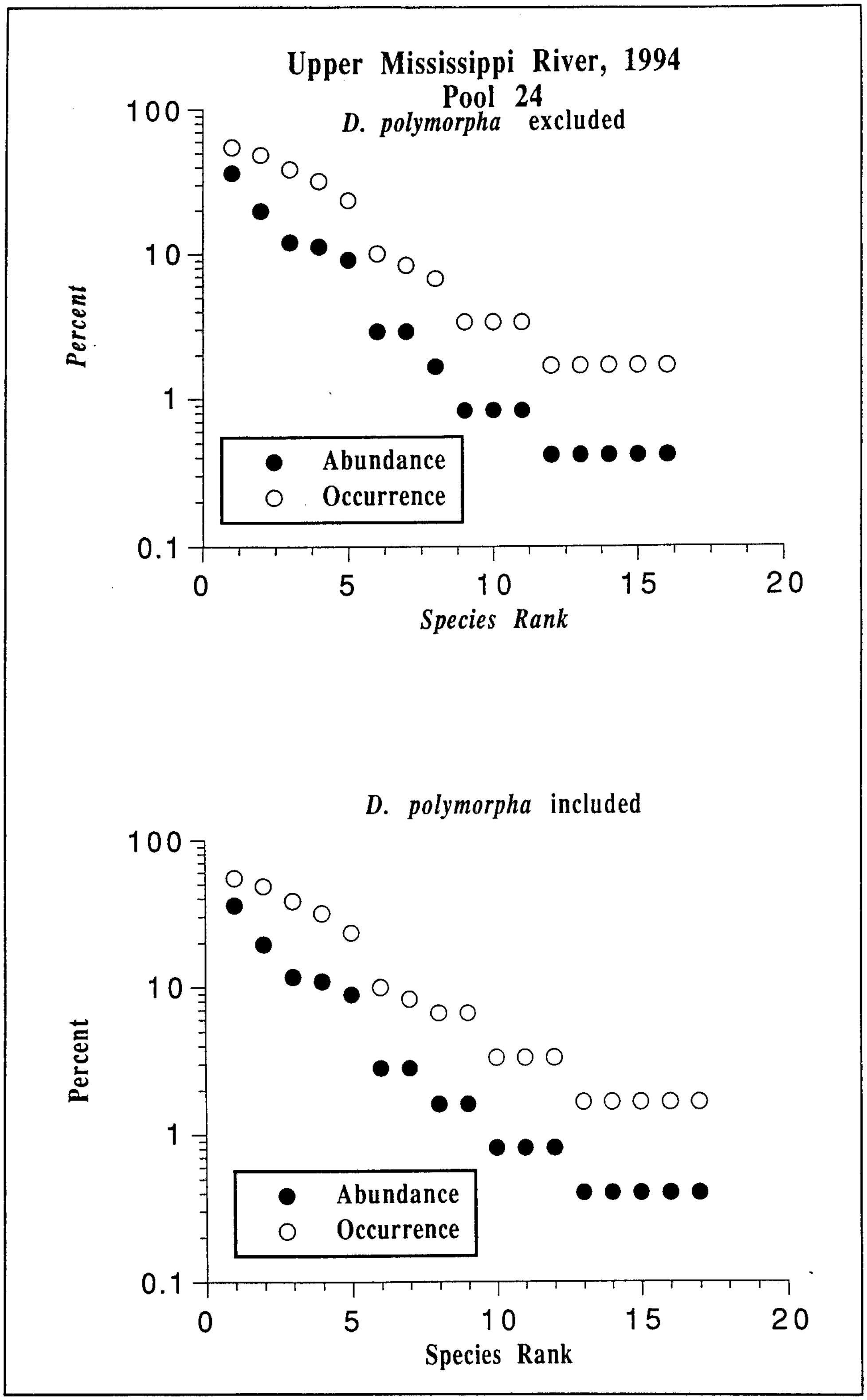

Figure 12. Species rank versus percent abundance and occurrence of all mussels collected (with and without consideration of *D. polymorpha*) for mussel bed in Pool 24, UMR, 1994

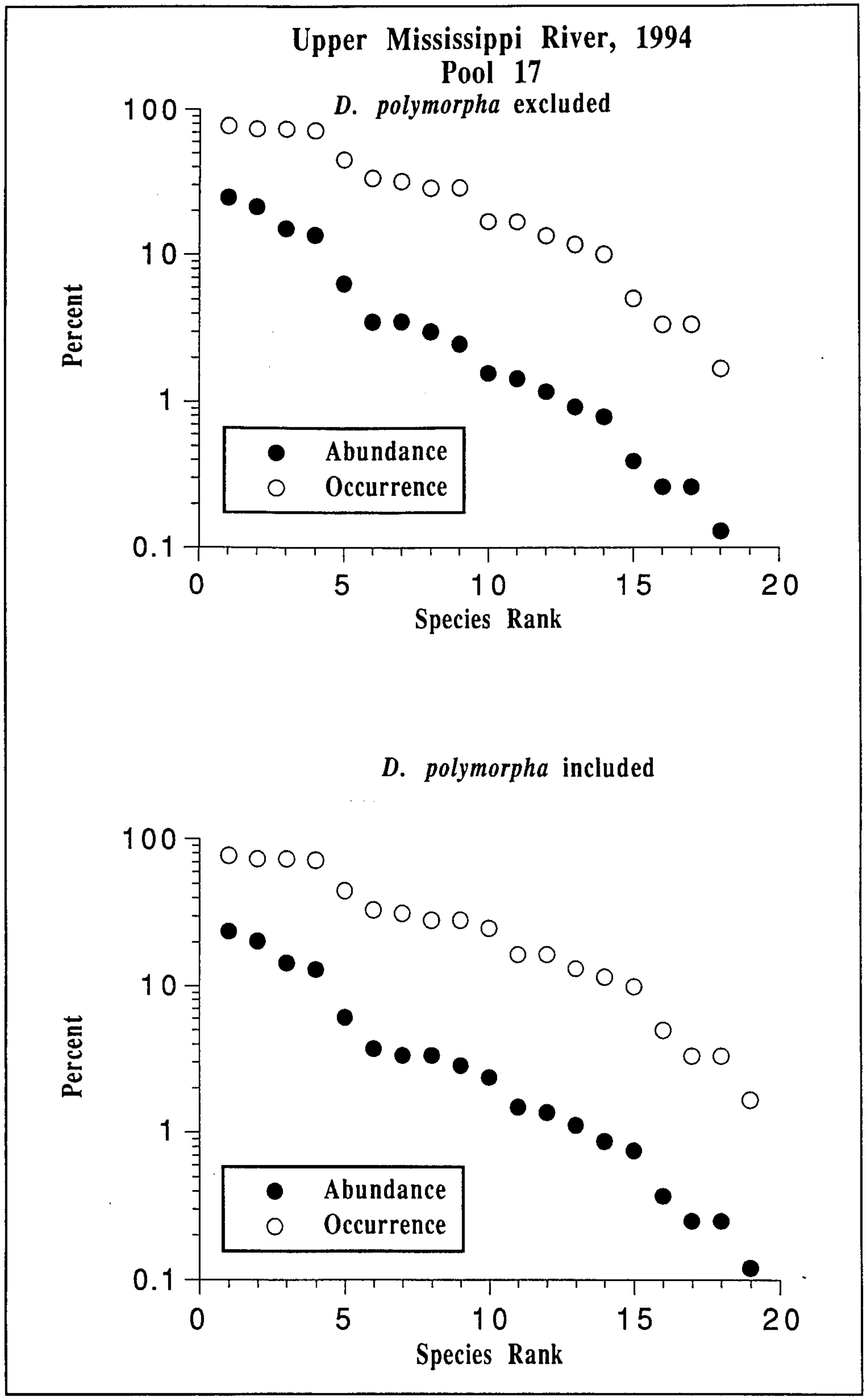

Figure 13. Species rank versus percent abundance and occurrence of all mussels collected (with and without consideration of *D. polymorpha*) for mussel bed in Pool 17, UMR, 1994

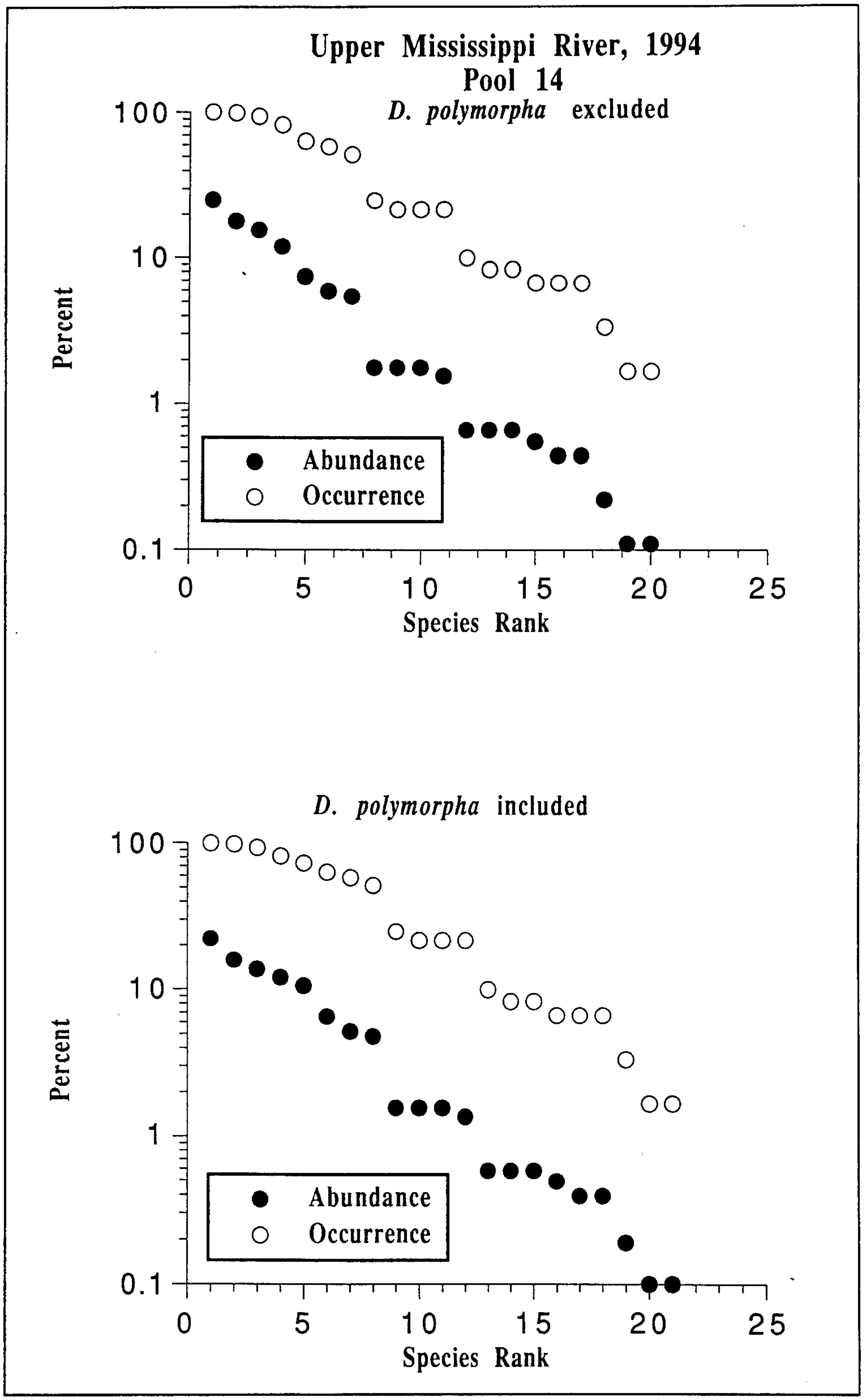

Figure 14. Species rank versus percent abundance and occurrence of all mussels collected (with and without consideration of *D. polymorpha*) for mussel bed in Pool 14, UMR, 1994

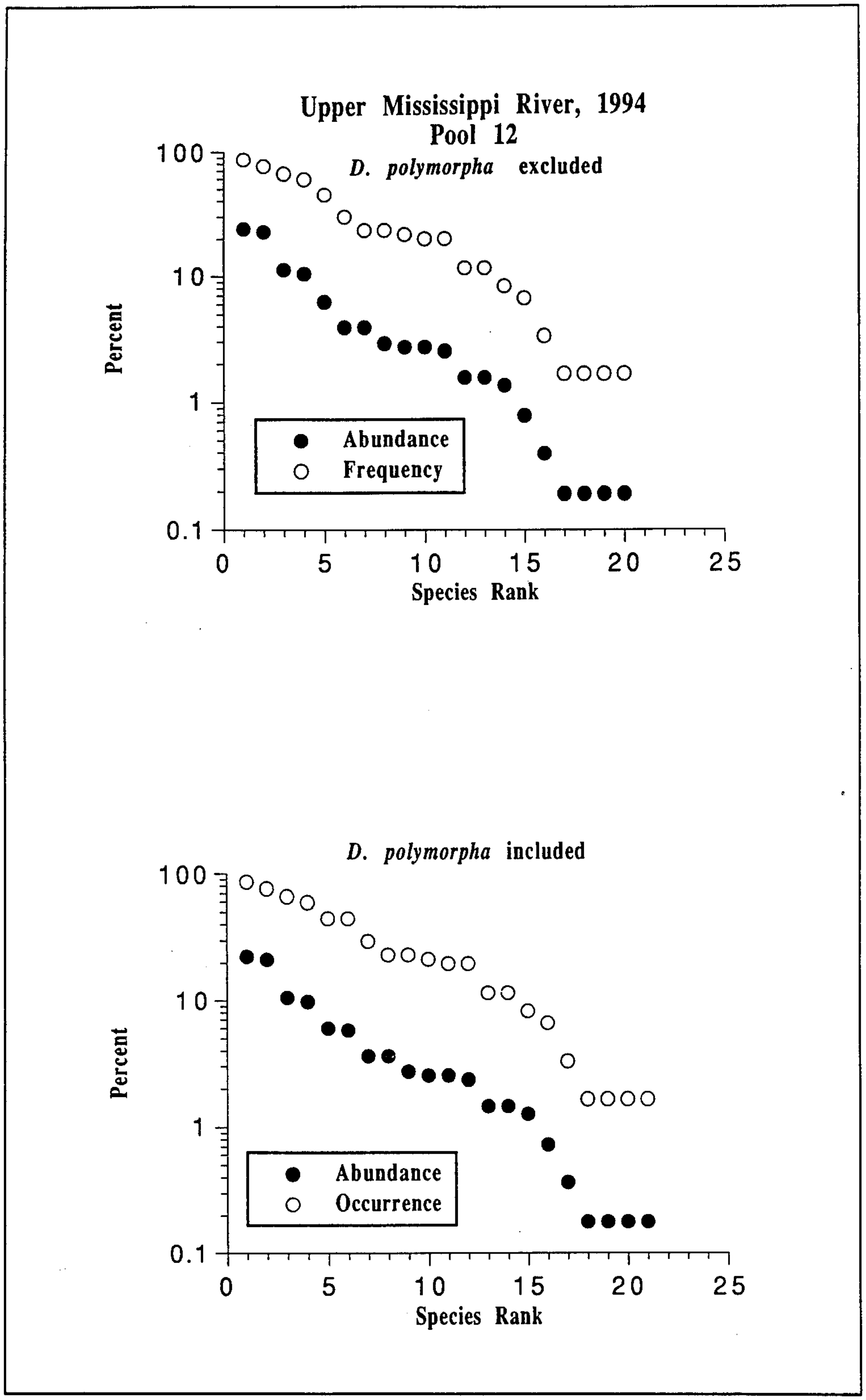

Figure 15. Species rank versus percent abundance and occurrence of all mussels collected (with and without consideration of *D. polymorpha*) for mussel bed in Pool 12, UMR, 1994

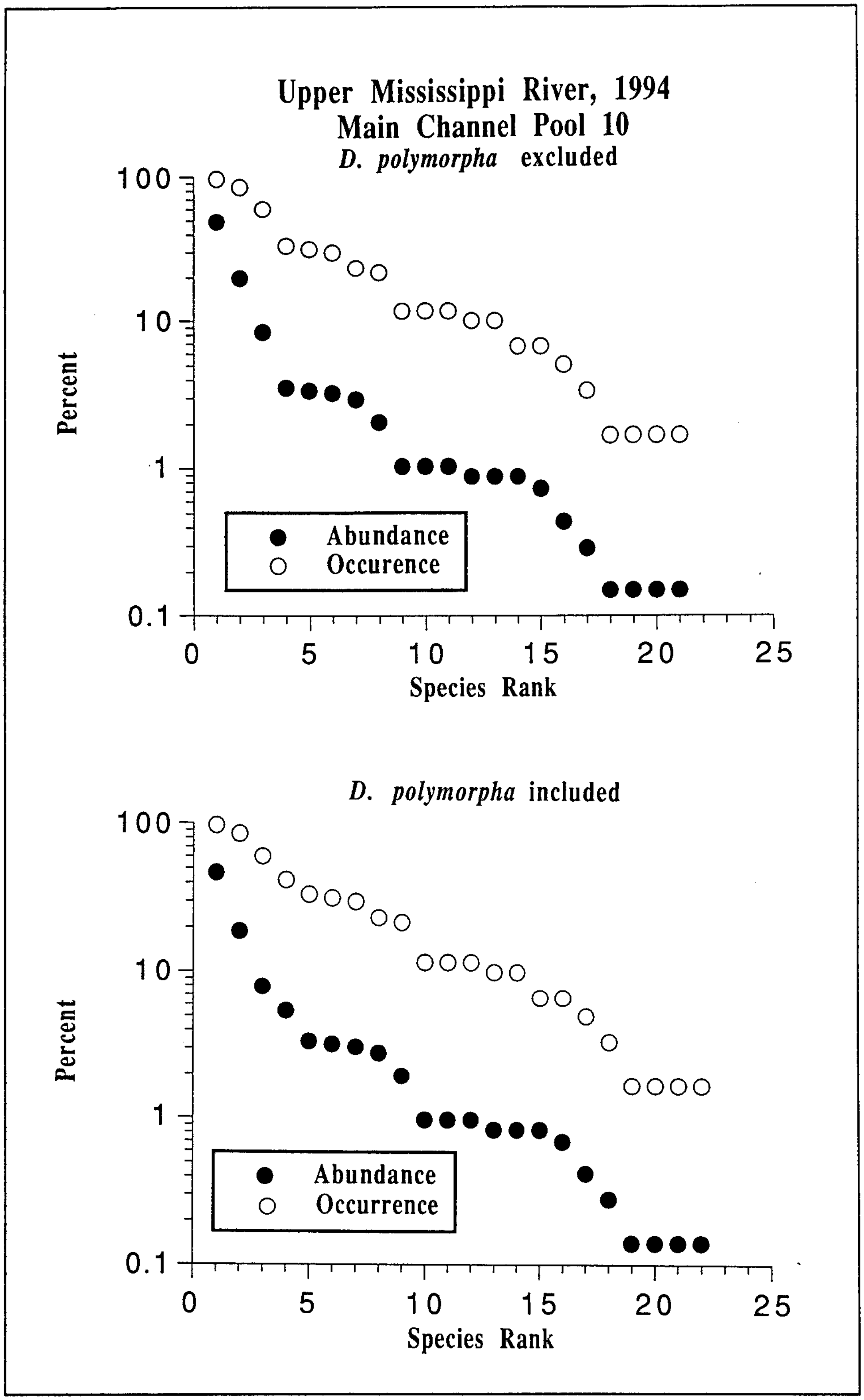

Figure 16. Species rank versus percent abundance and occurrence of all mussels collected (with and without consideration of *D. polymorpha*) for mussel bed in Pool 10, UMR, 1994

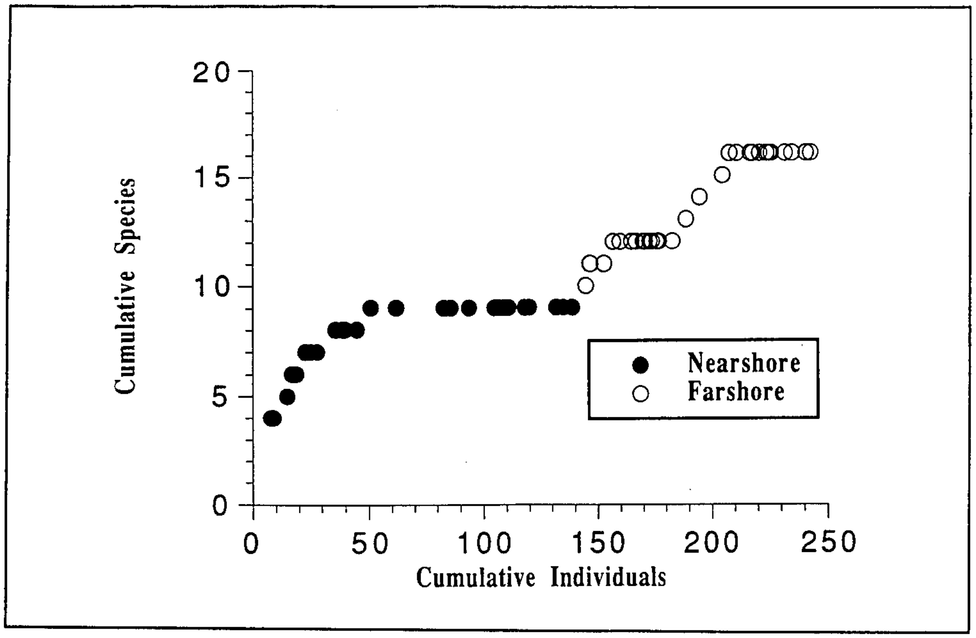

Figure 17. Cumulative number of species versus cumulative number of individuals collected at mussel bed in Pool 24, UMR, 1994

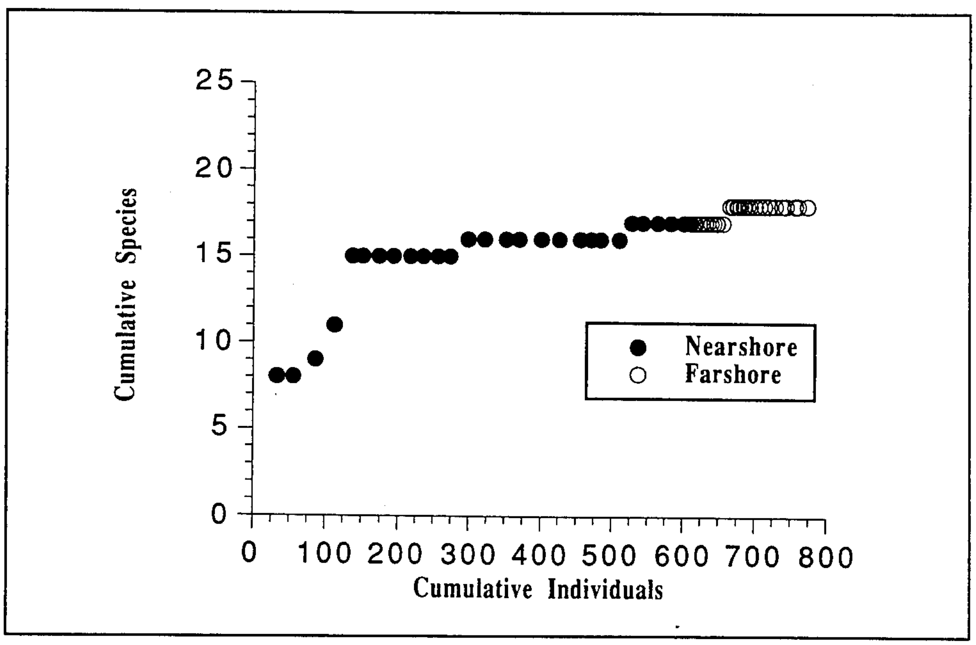

Figure 18. Cumulative number of species versus cumulative number of individuals collected at mussel bed in Pool 17, UMR, 1994

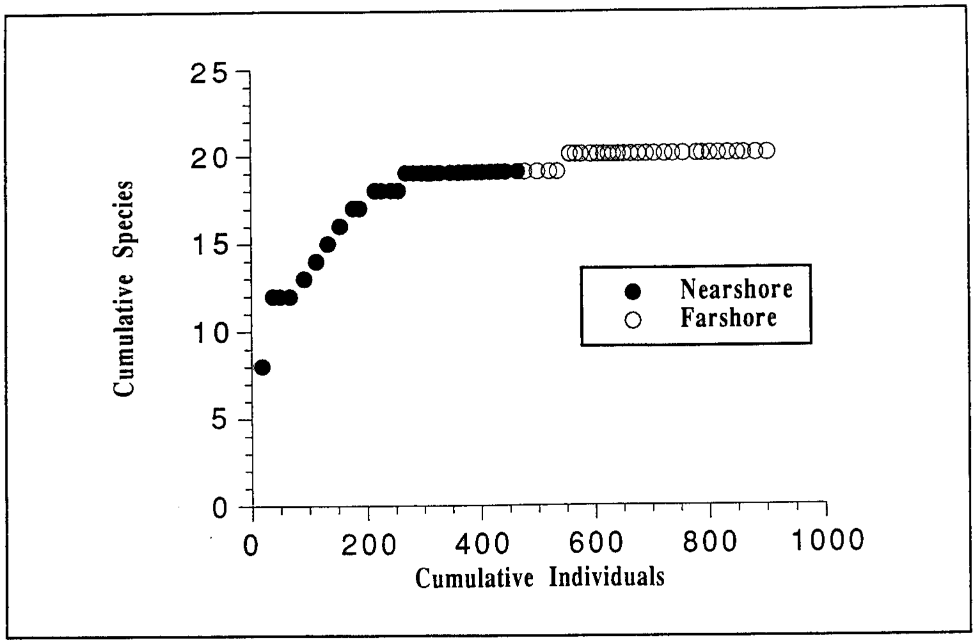

Figure 19. Cumulative number of species versus cumulative number of individuals collected at mussel bed in Pool 14, UMR, 1994

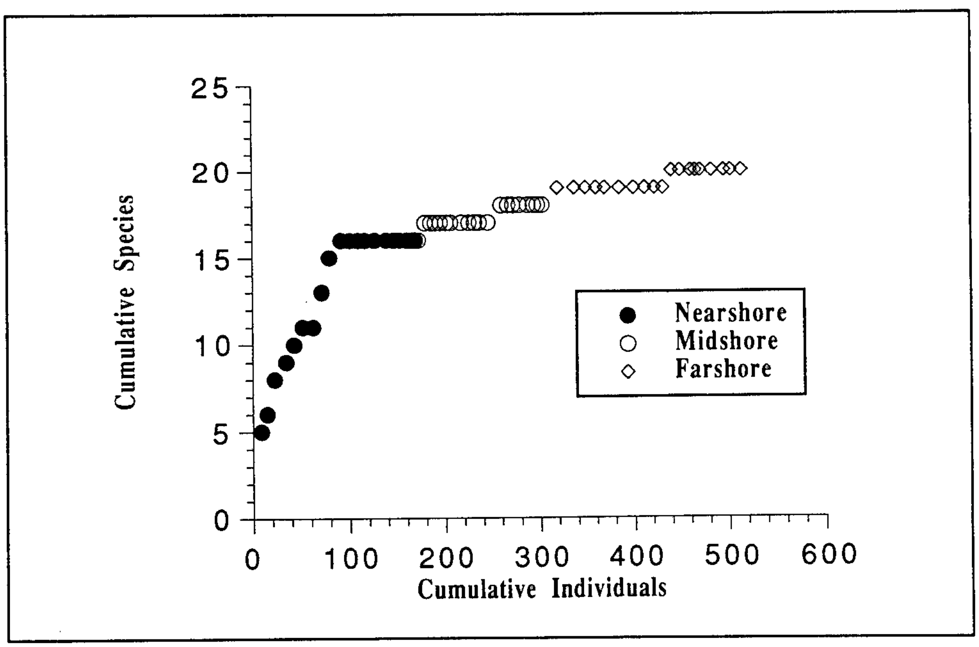

Figure 20. Cumulative number of species versus cumulative number of individuals collected at mussel bed in Pool 12, UMR, 1994

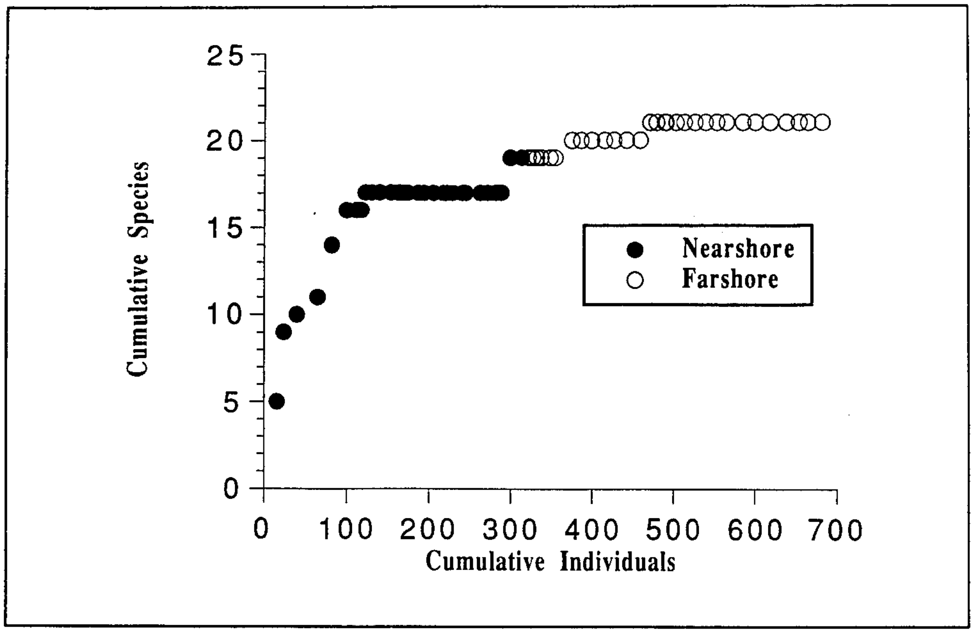

Figure 21. Cumulative number of species versus cumulative number of individuals collected at mussel bed in Pool 10, UMR, 1994

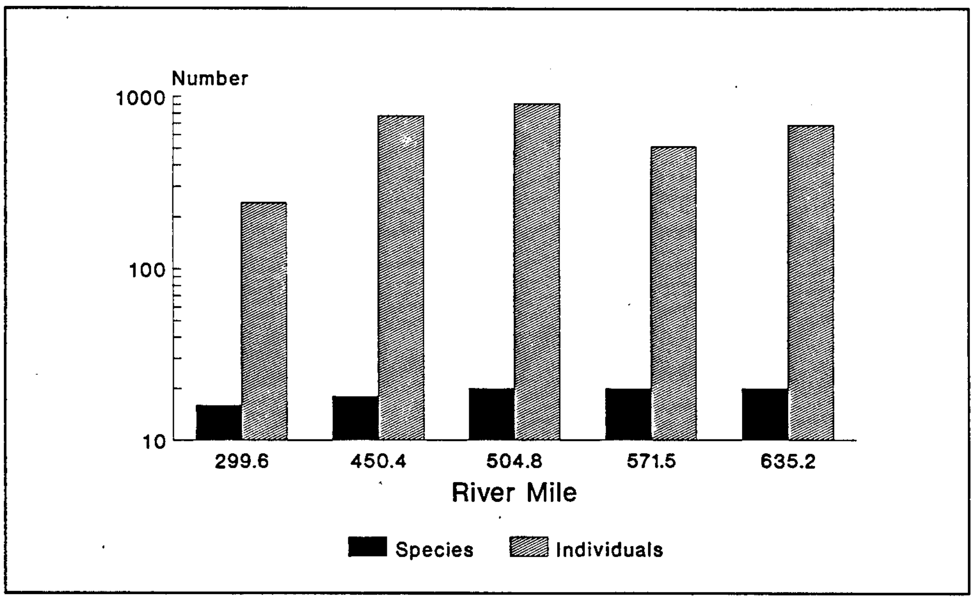

Figure 22. Number of individuals and species of freshwater mussels collected at five mussel beds in UMR, 1994

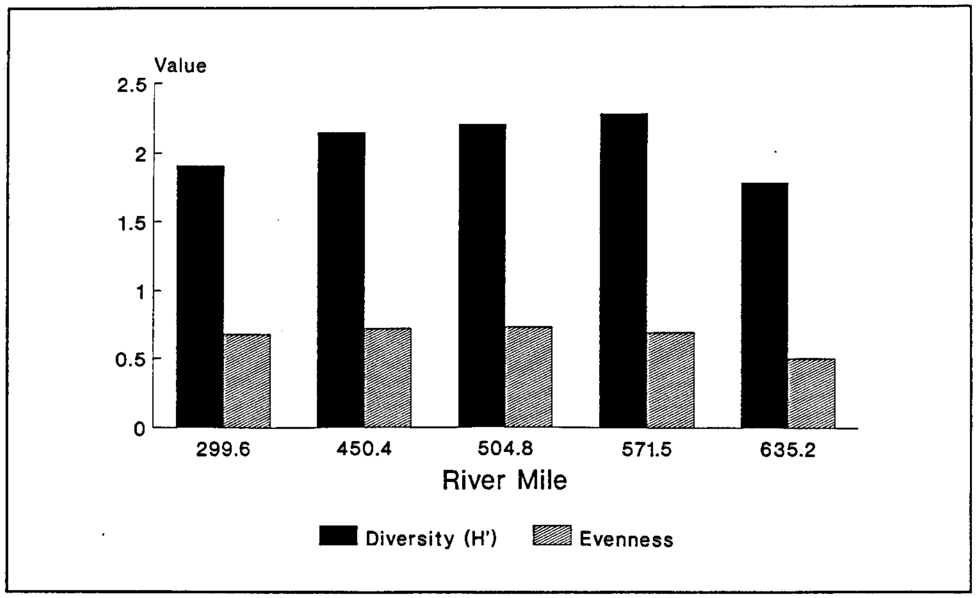

Figure 23. Species diversity (H′) and evenness at five mussel beds, UMR, 1994

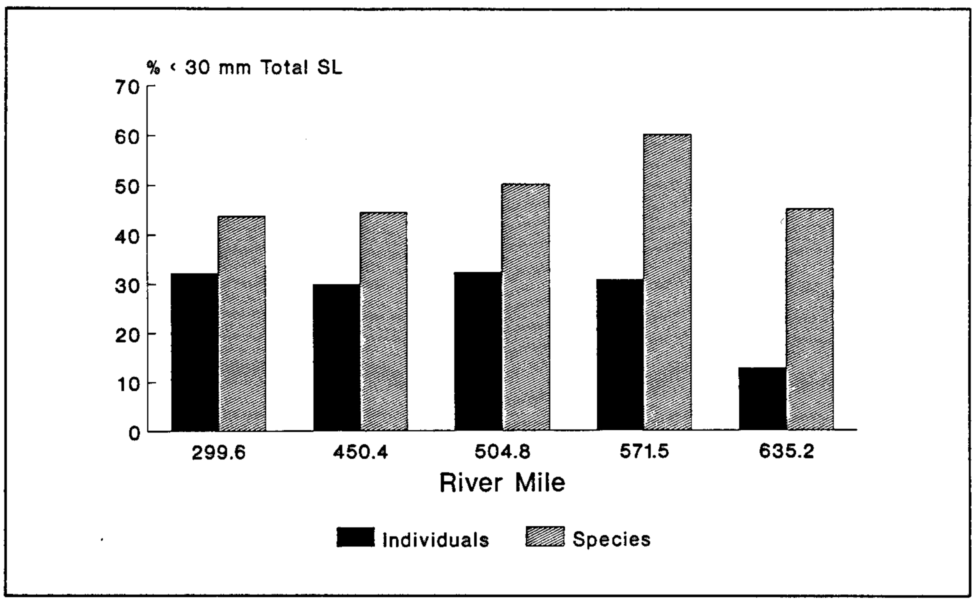

Figure 24. Evidence of recent recruitment at five mussel beds, UMR, 1994

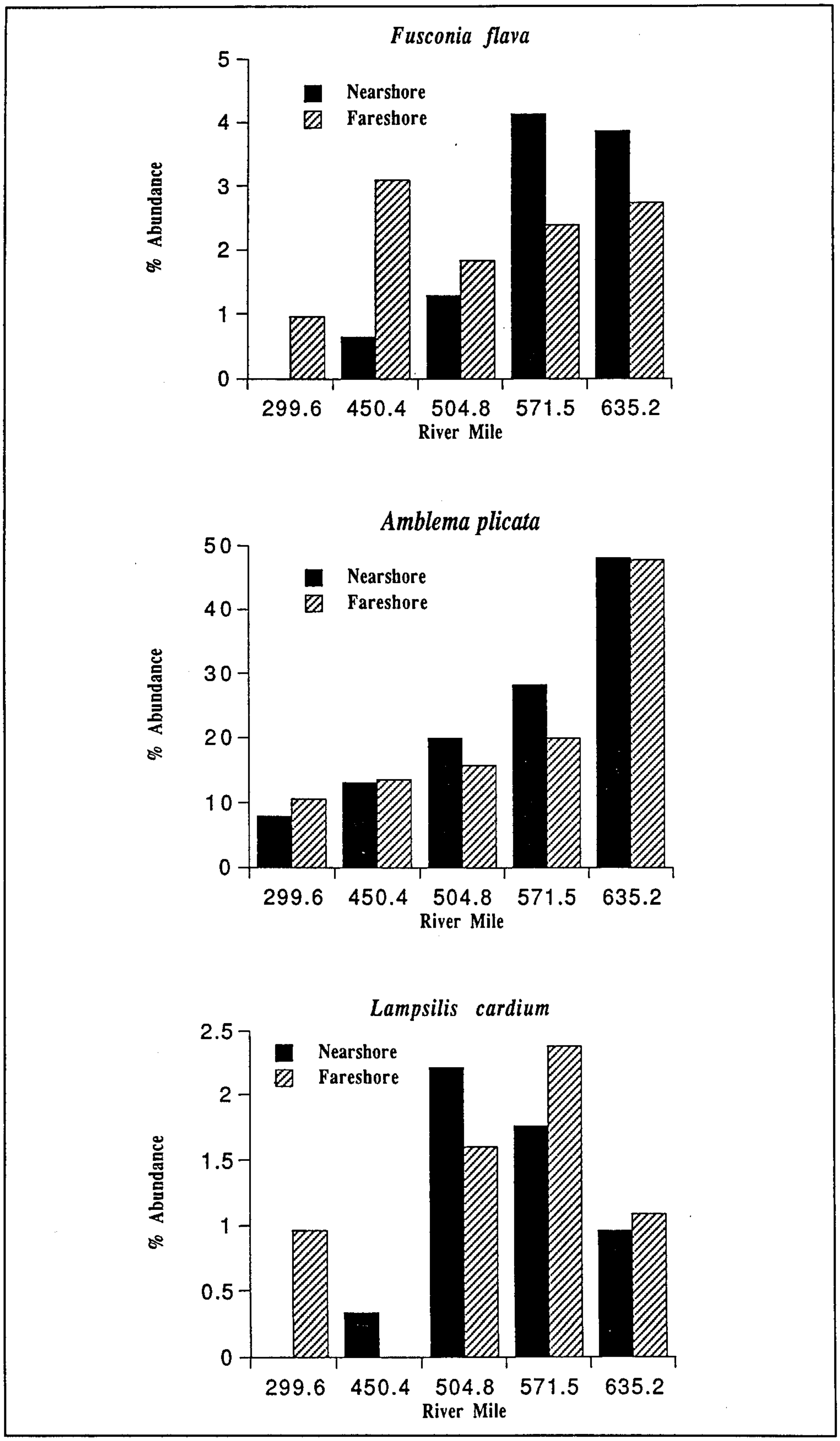

Figure 25. Three species of native mussels that become more common moving upriver in UMR

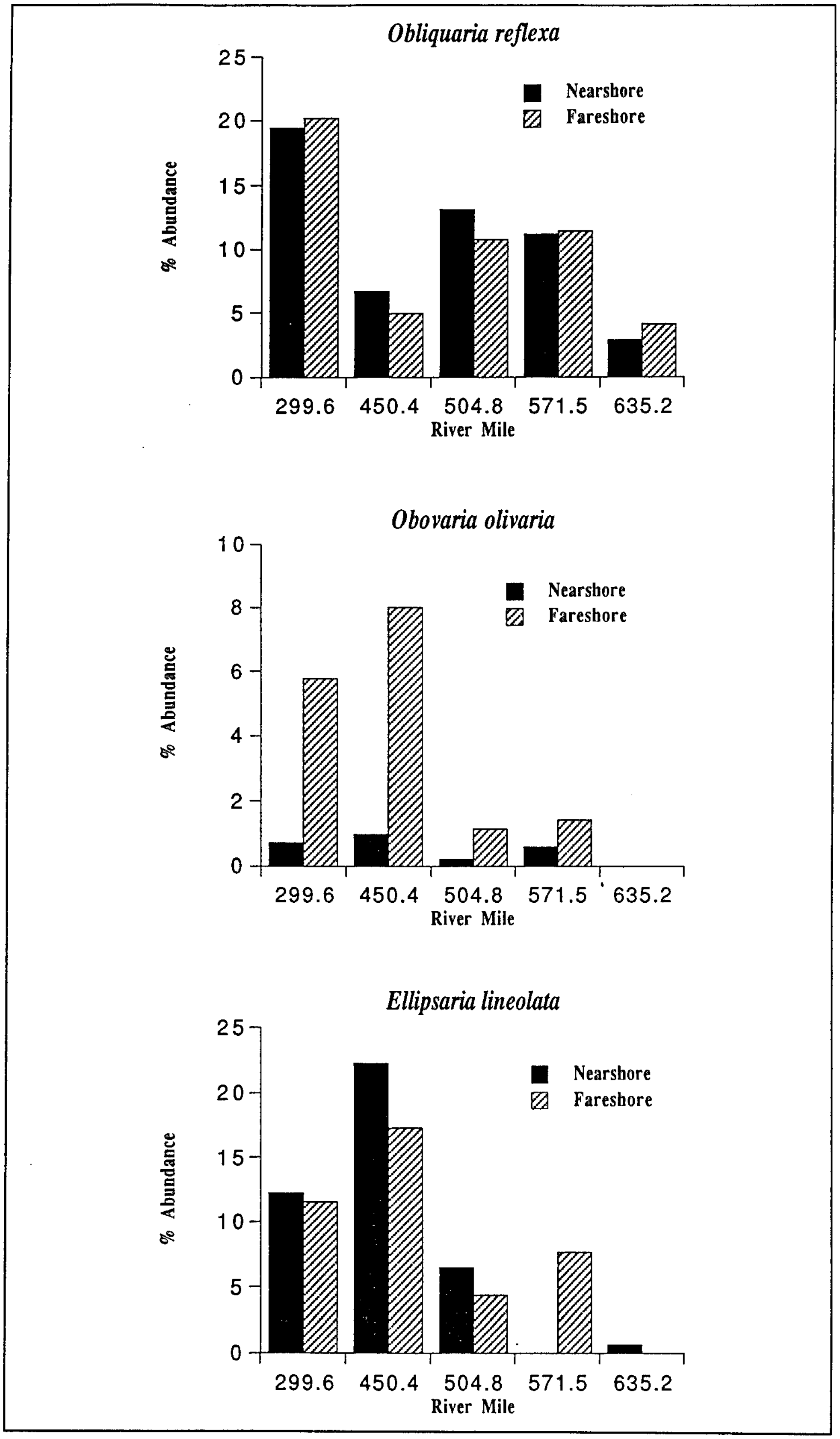

Figure 26. Three species of native mussels that become less common moving upriver in UMR

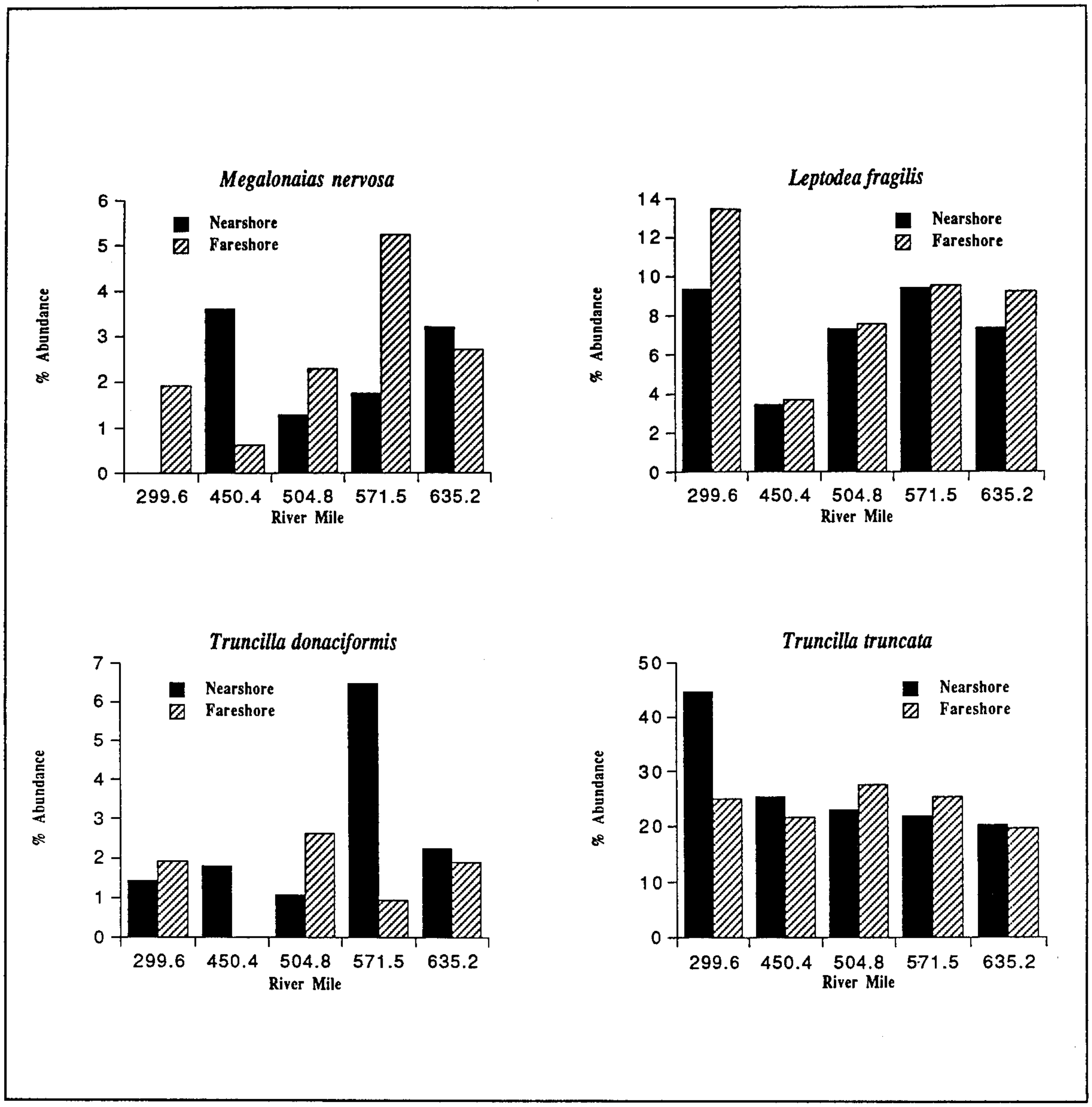

Figure 27. Four species of native mussels in UMR that exhibit no specific trends in abundance with respect to river mile or distance to shore

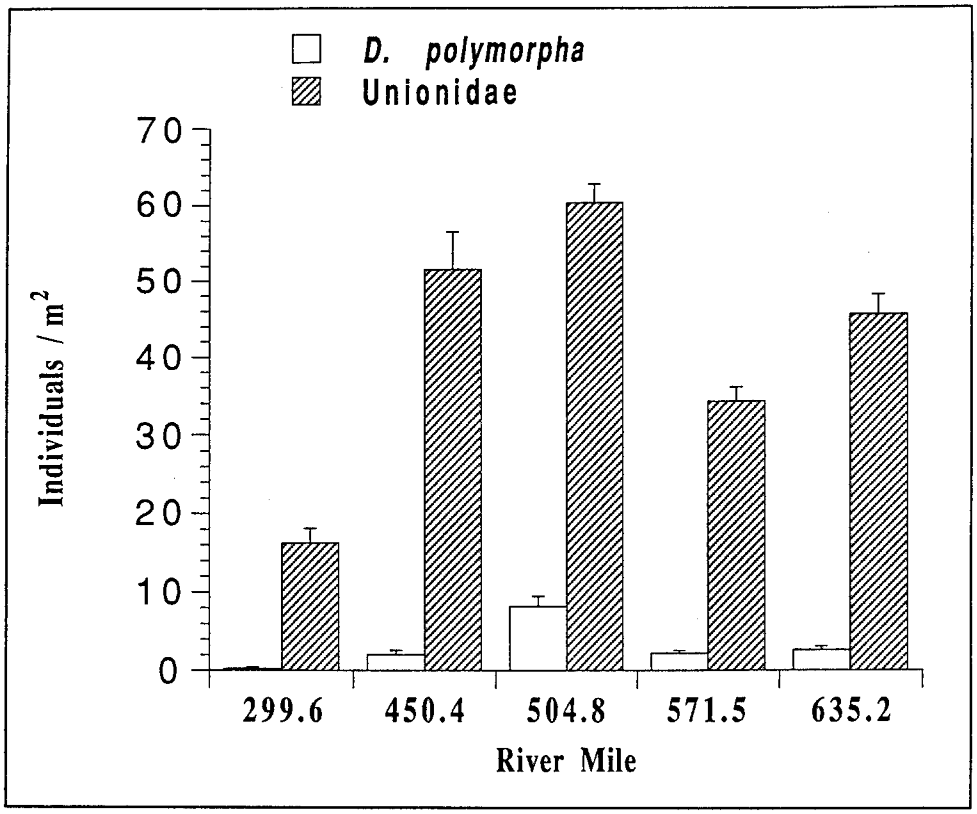

Figure 28. Total mean density (individuals/square meter) of native mussels and *D. polymorpha* at five mussel beds, UMR, 1994

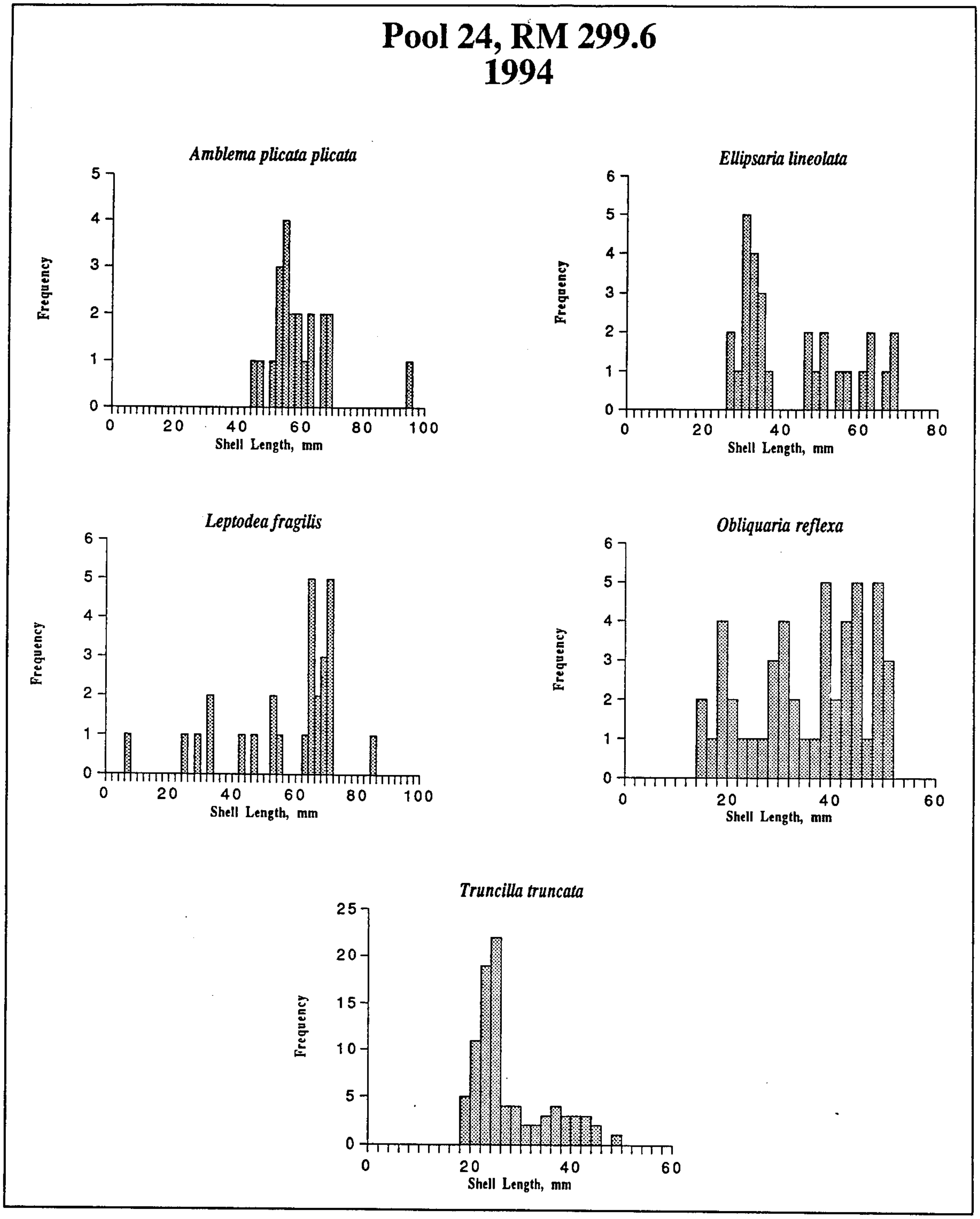

Figure 29. Length-frequency histograms for freshwater mussels collected at mussel bed located in Pool 24, UMR, 1994

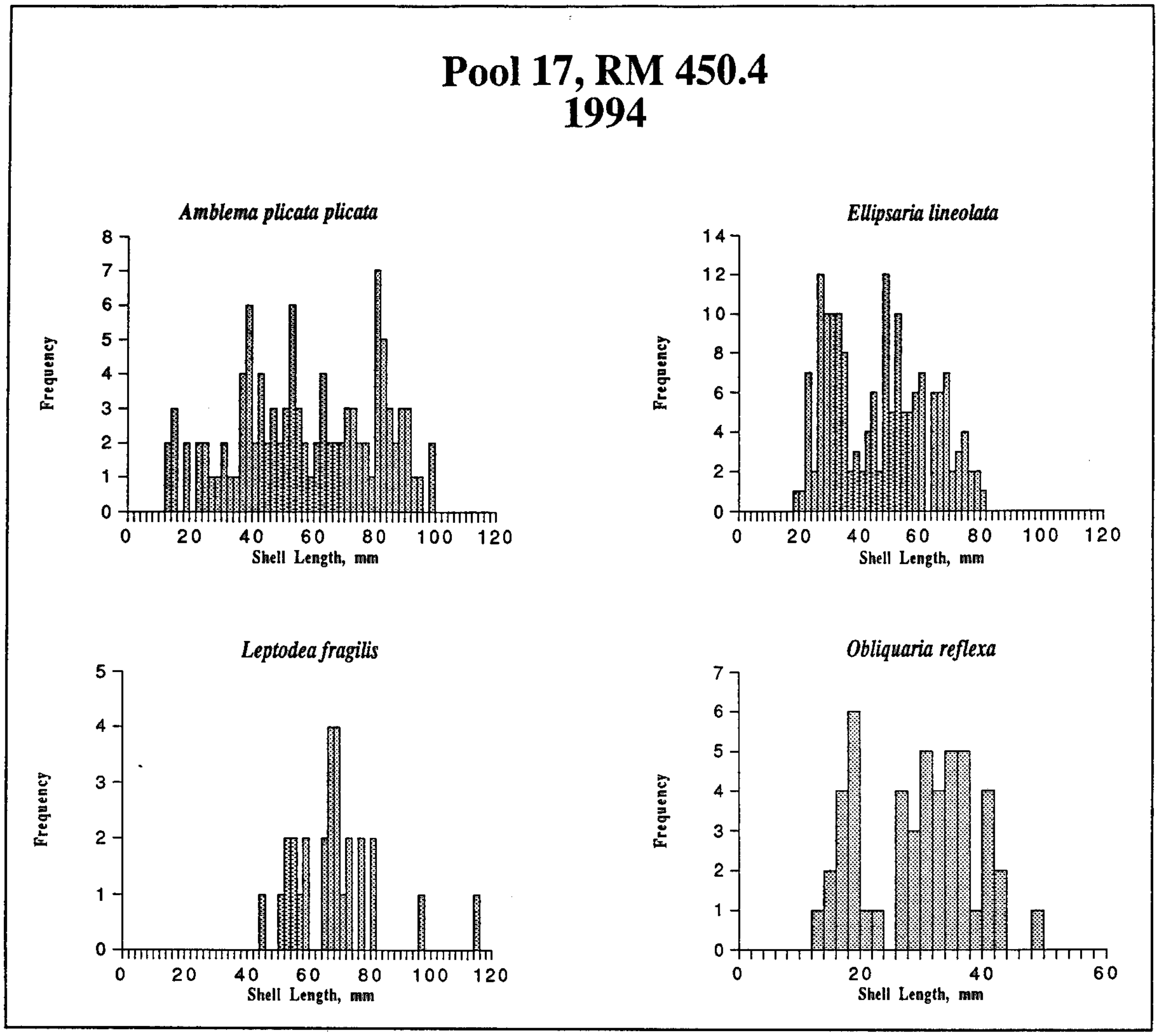

Figure 30. Length-frequency histograms for freshwater mussels collected at mussel bed located in Pool 17, UMR, 1994 (Continued)

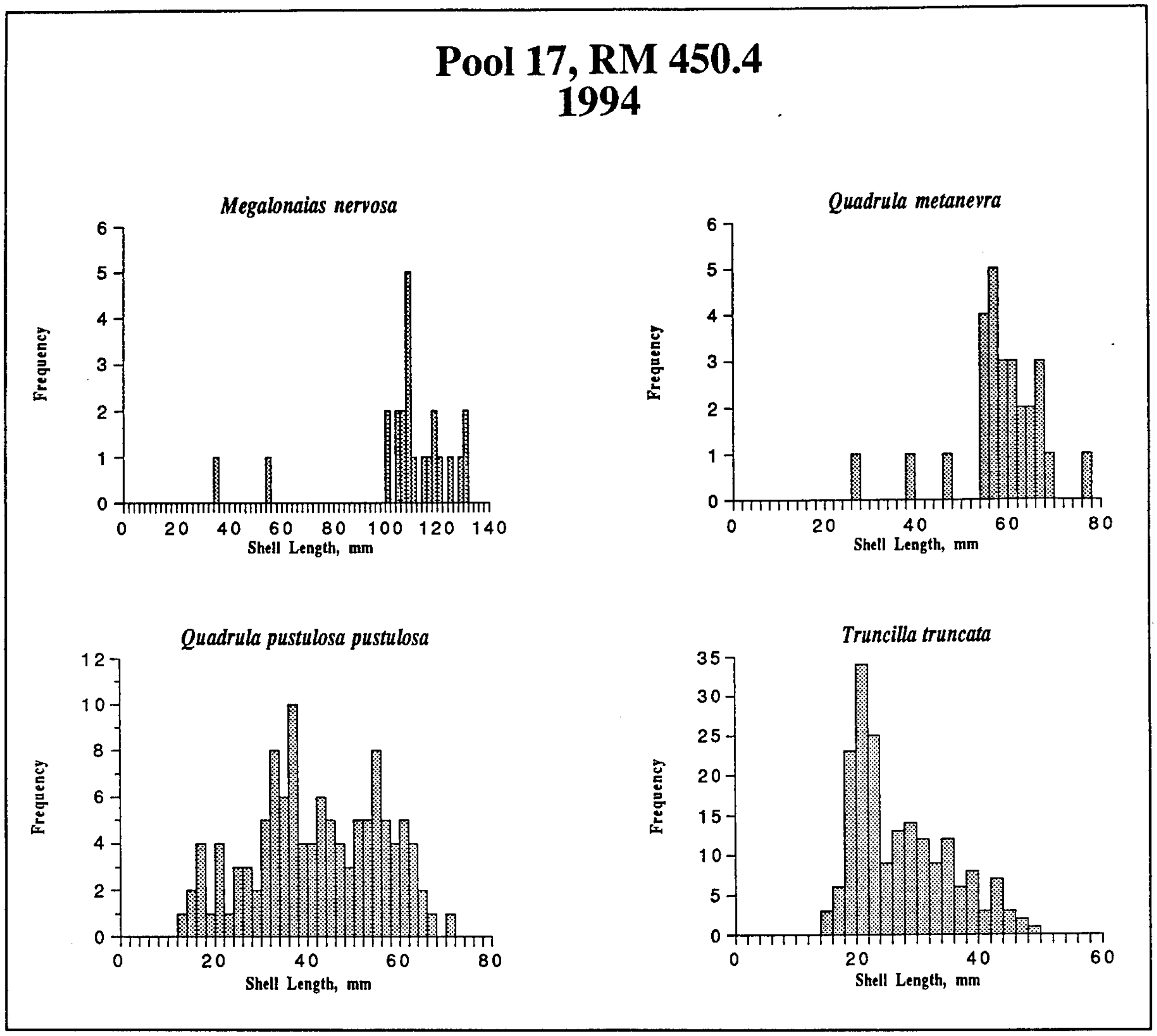

Figure 30. (Concluded)

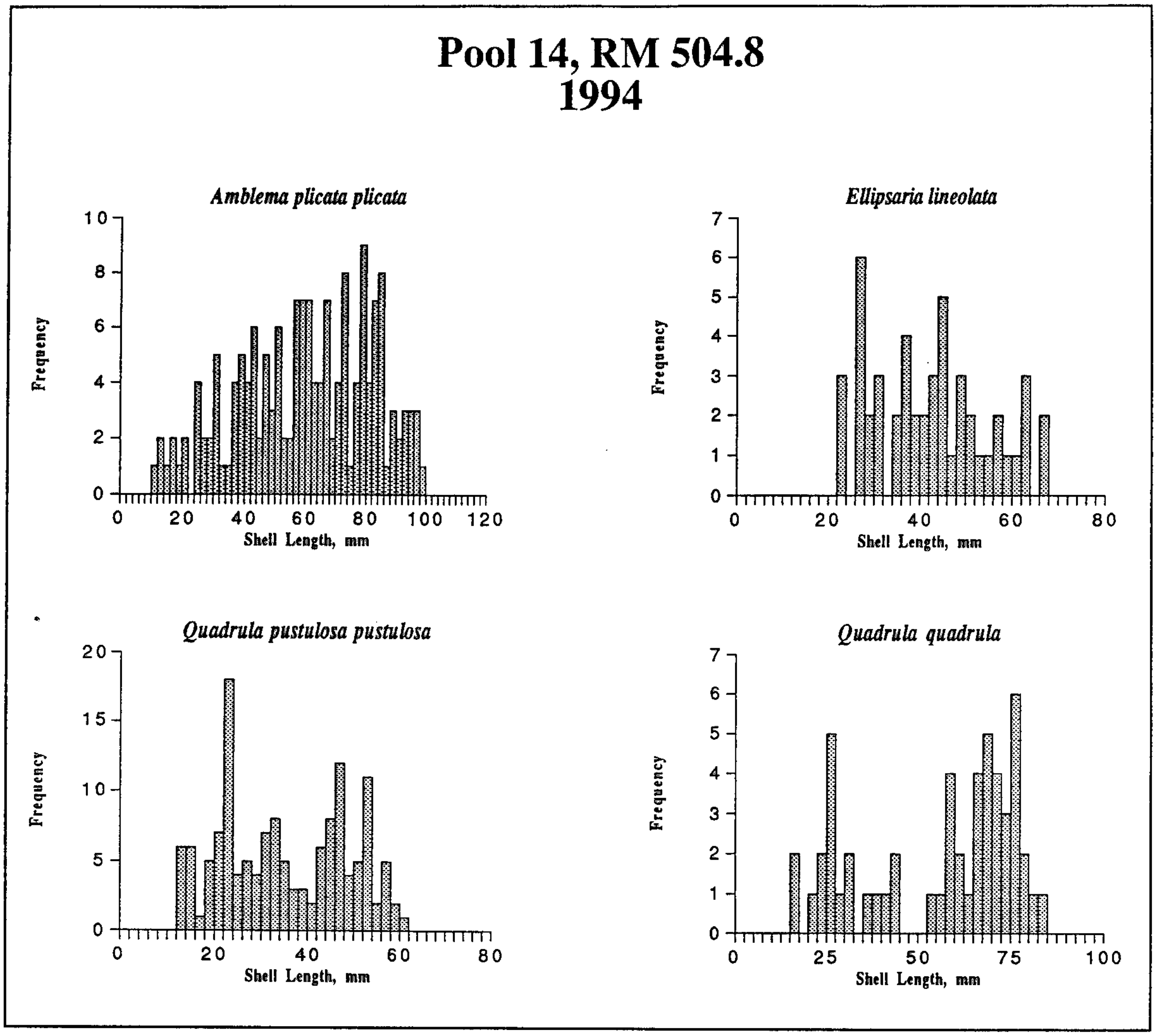

Figure 31. Length-frequency histograms for freshwater mussels collected at mussel bed located in Pool 14, UMR, 1994 (Continued)

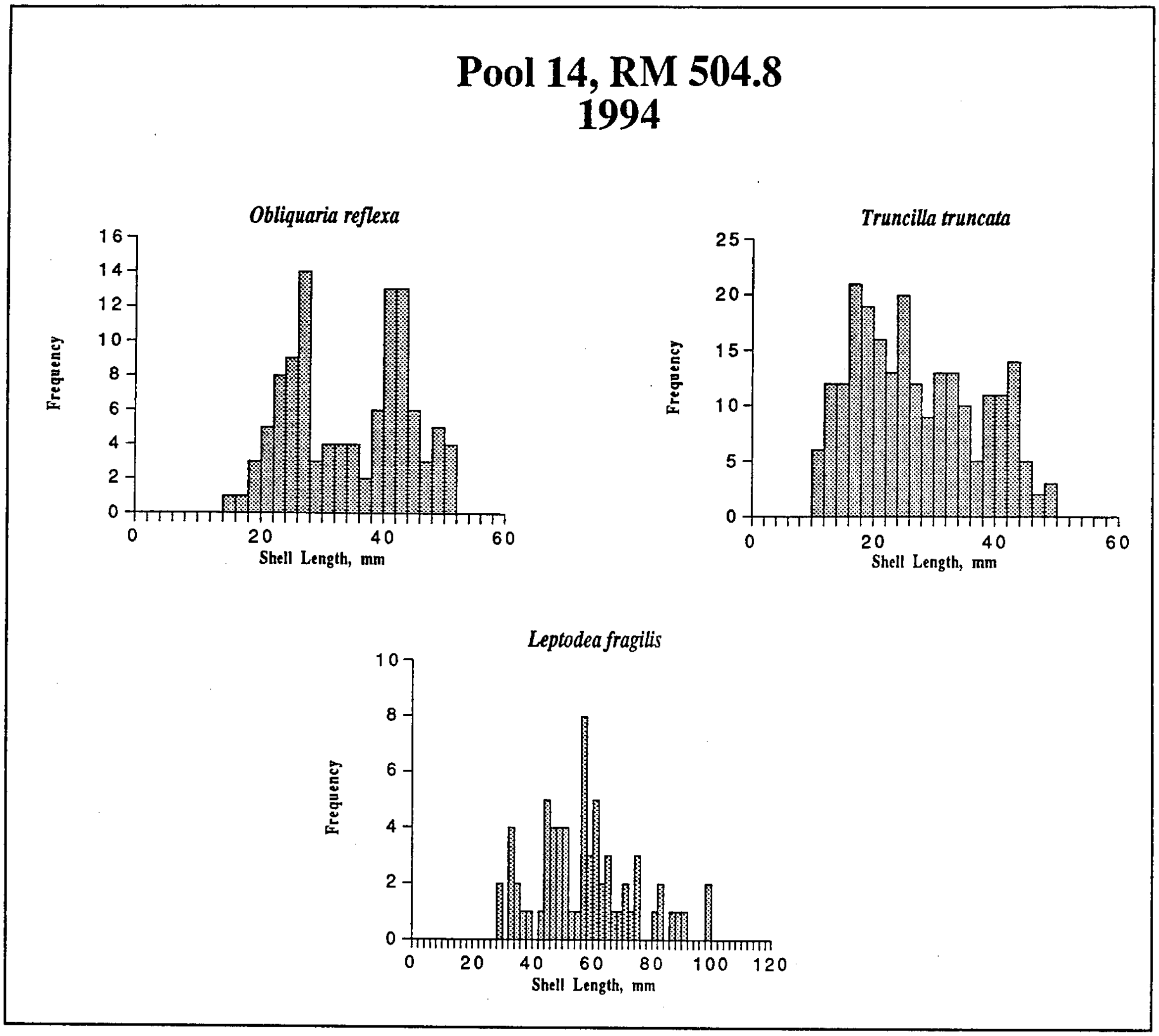

Figure 31. (Concluded)

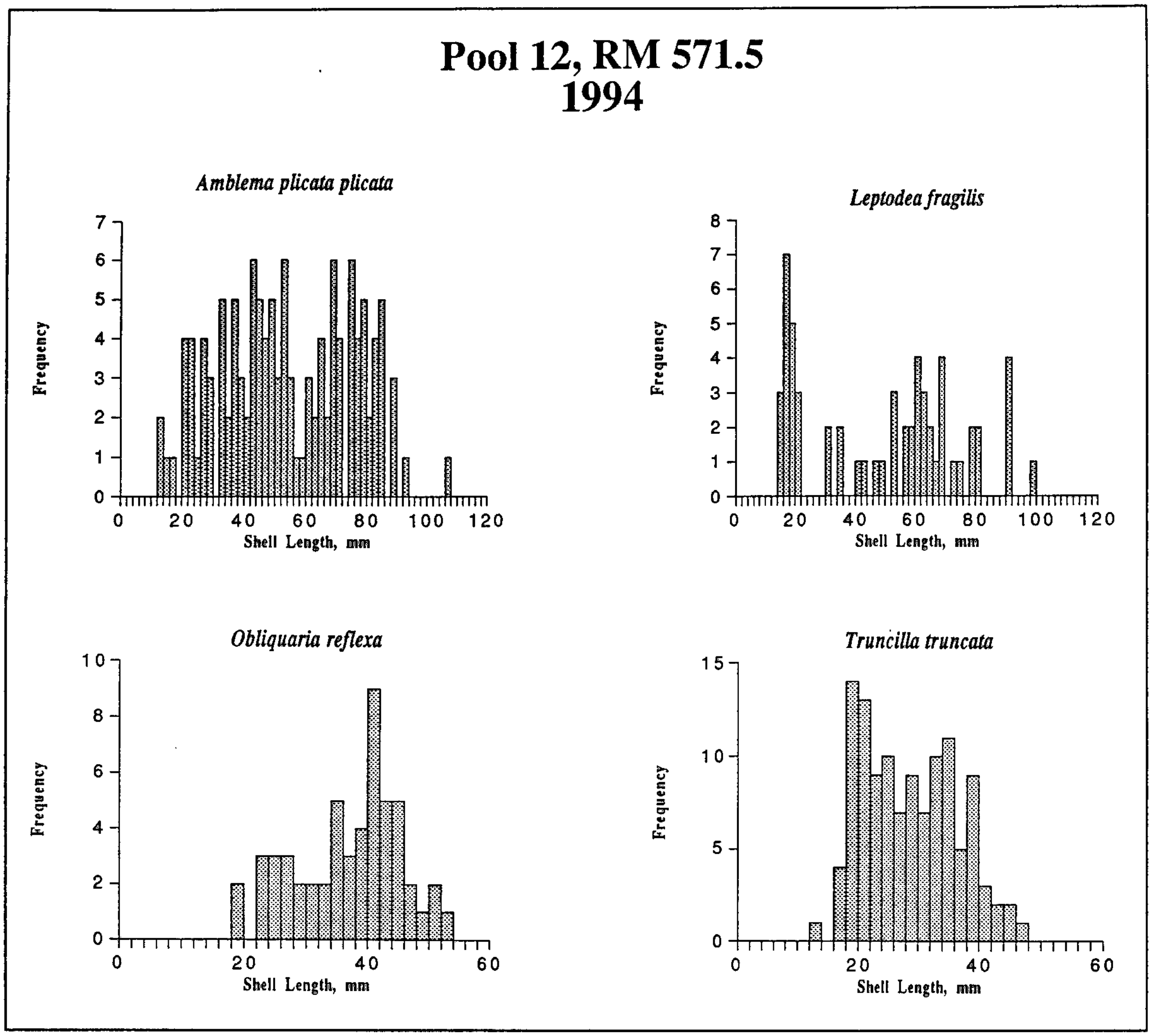

Figure 32. Length-frequency histograms for freshwater mussels collected at mussel bed located in Pool 12, UMR, 1994

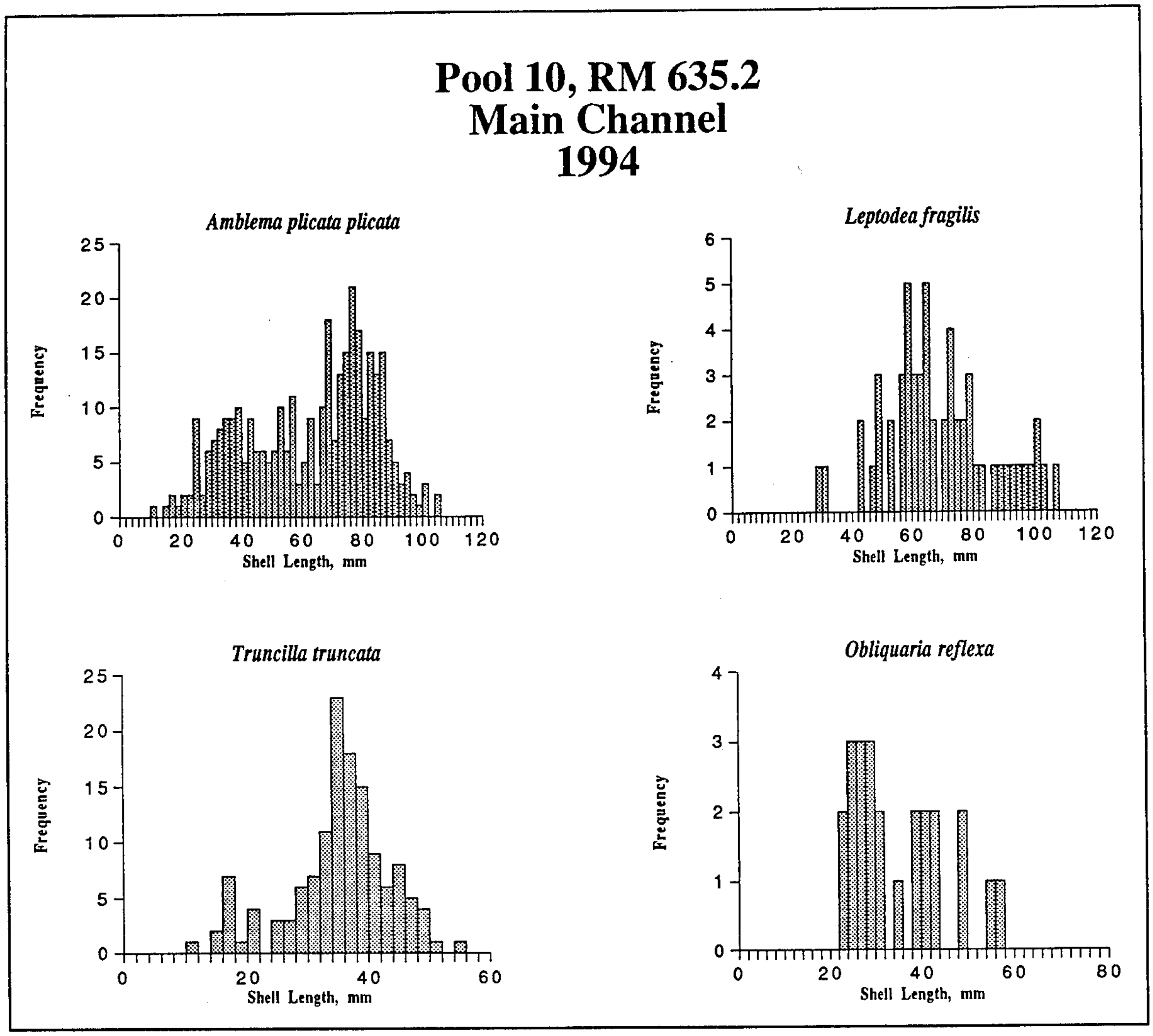

Figure 33. Length-frequency histograms for freshwater mussels collected at mussel bed located in Pool 10, UMR, 1994

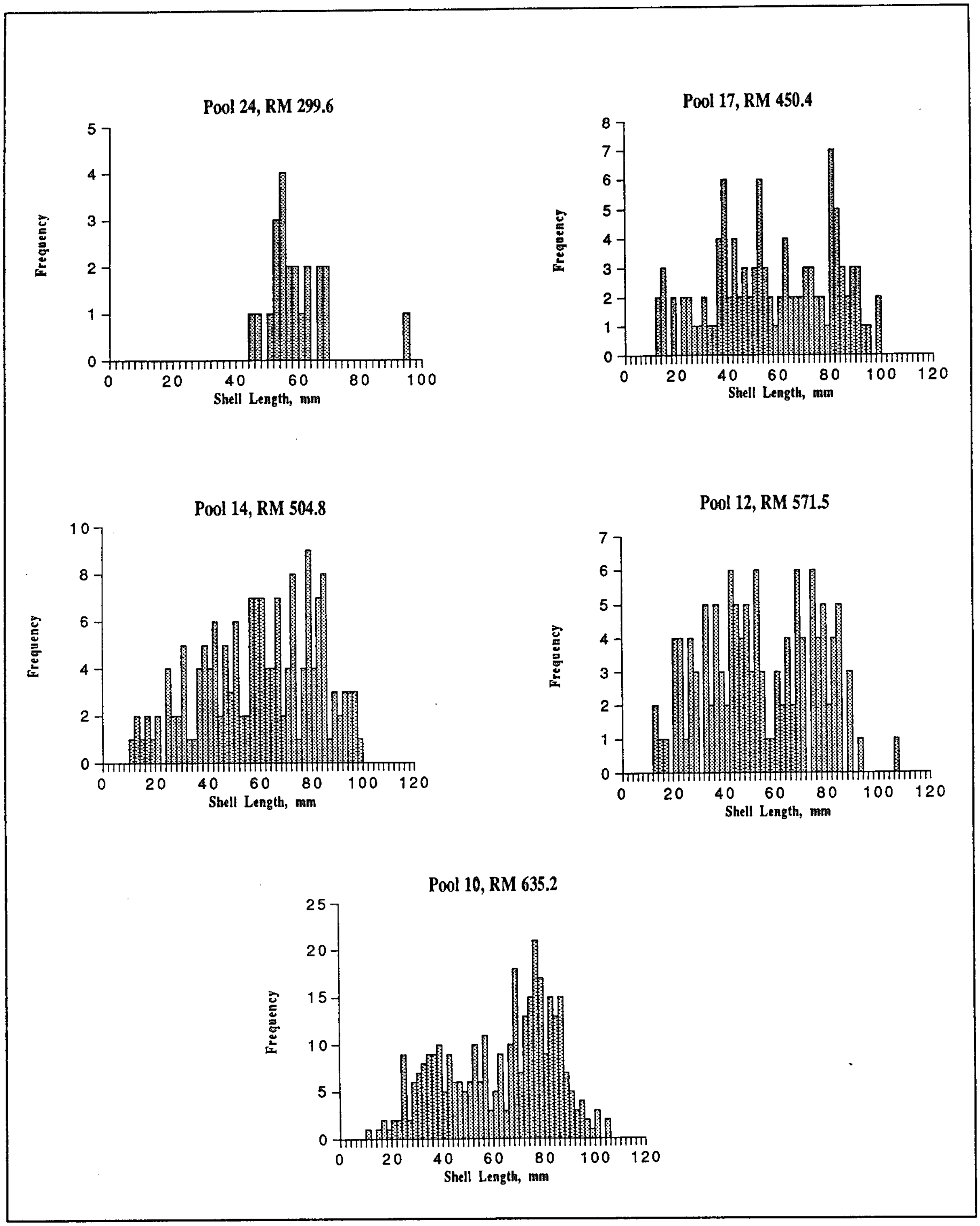

Figure 34. Interpool comparisons for *Amblema plicata plicata*, UMR, 1994

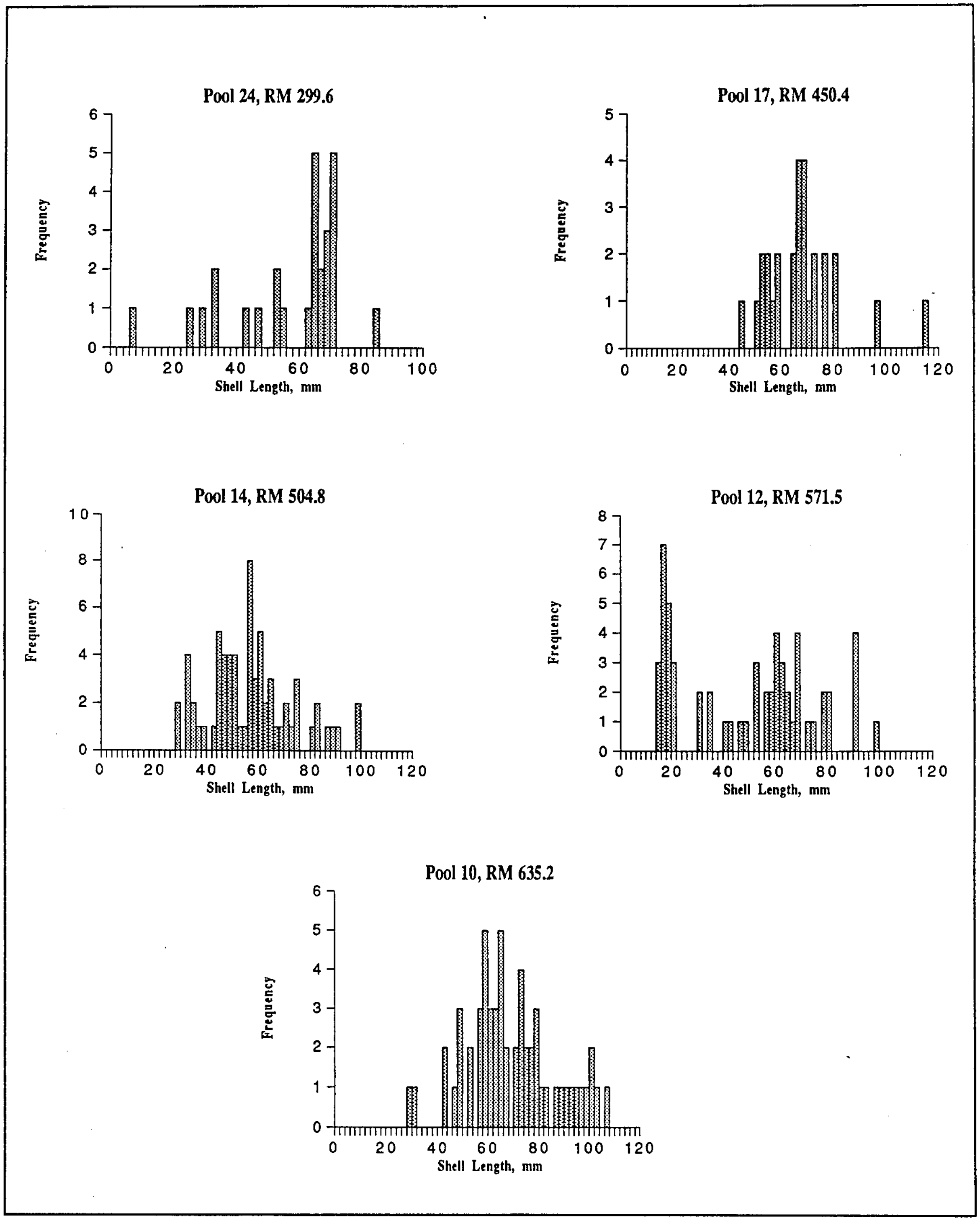

Figure 35. Interpool comparisons for *Leptodea fragilis*, UMR, 1994

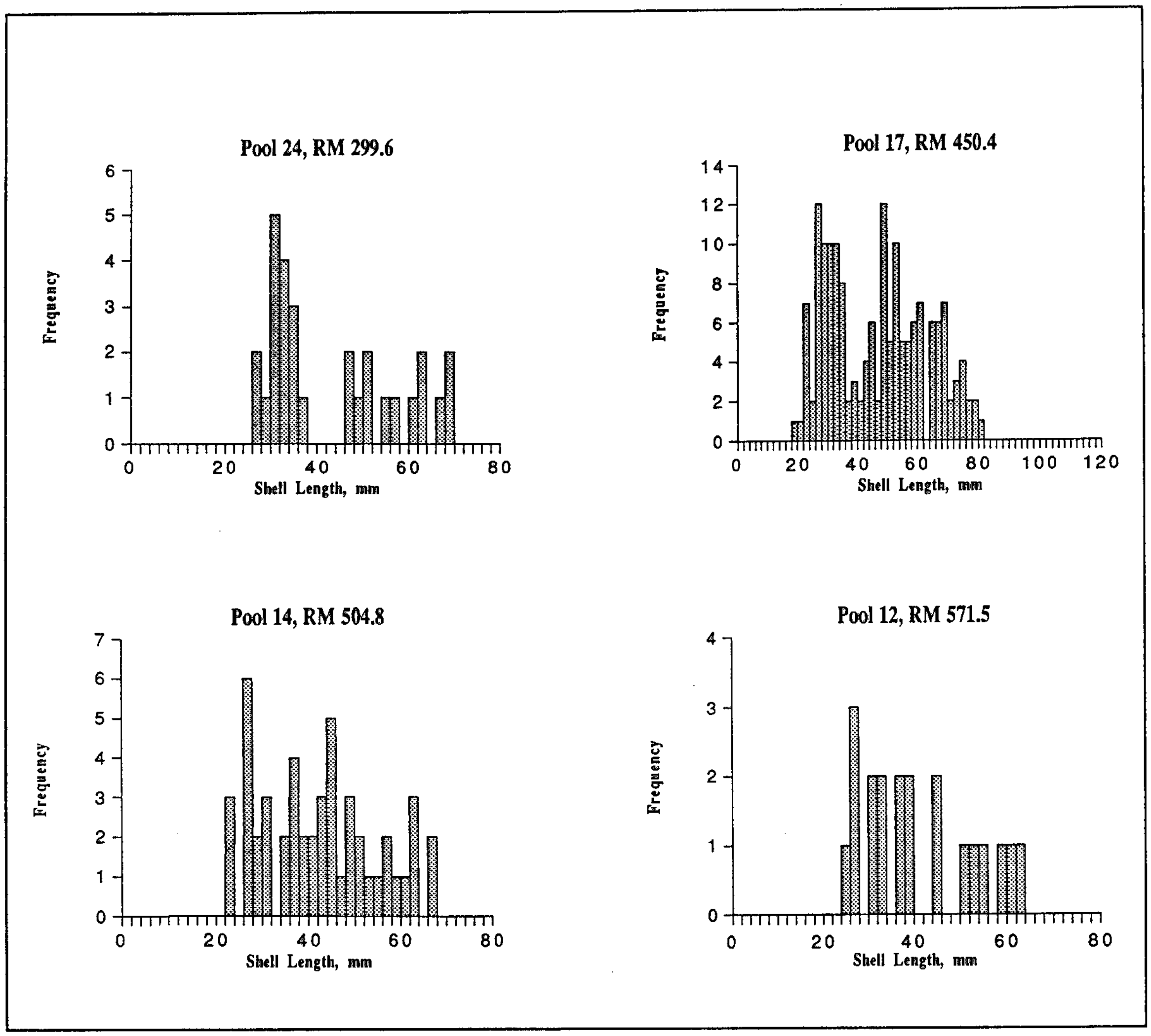

Figure 36. Interpool comparisons for *Ellipsaria lineolata*, UMR, 1994

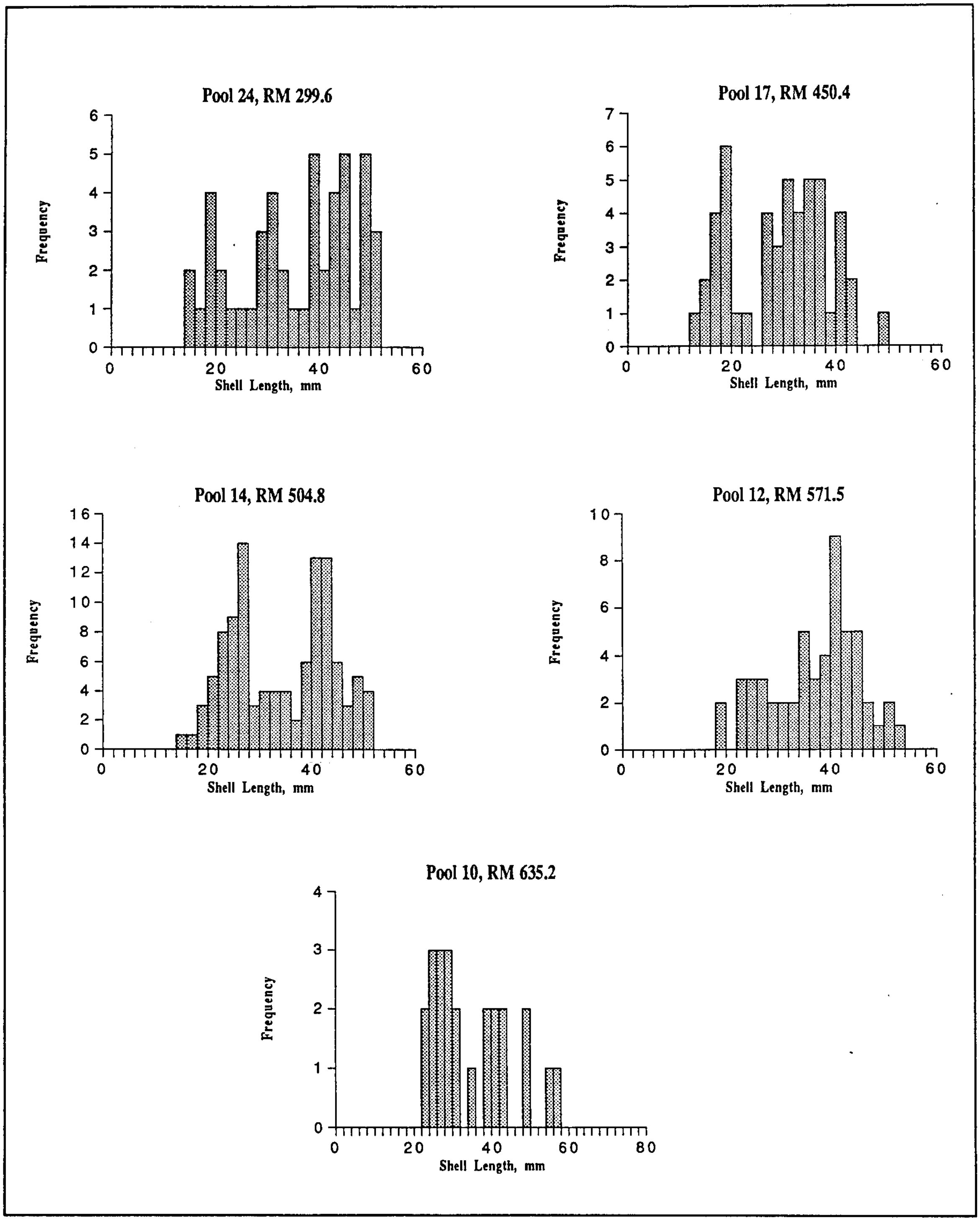

Figure 37. Interpool comparisons for *Obliquaria reflexa*, UMR, 1994

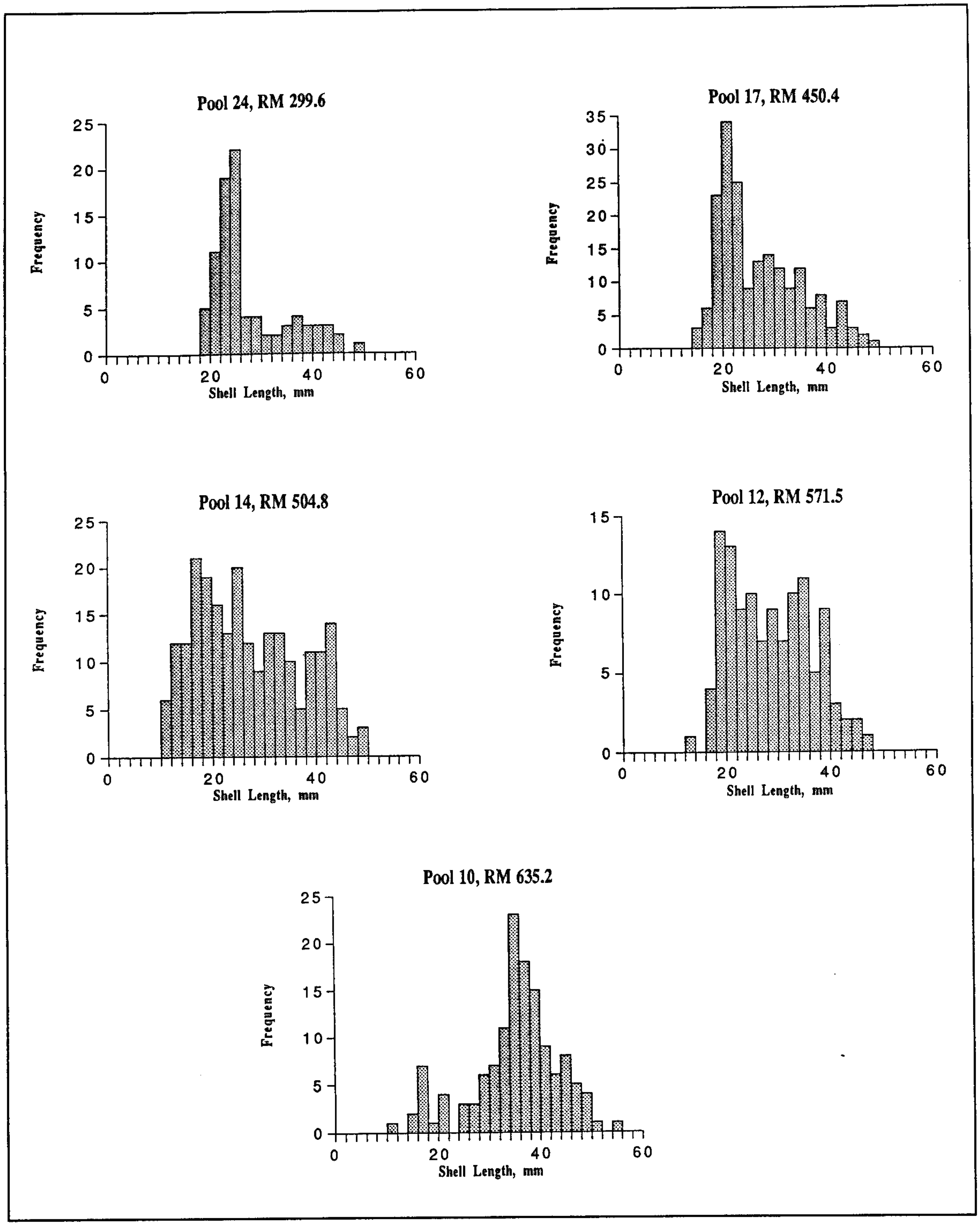

Figure 38. Interpool comparisons for *Truncilla truncata*, UMR, 1994

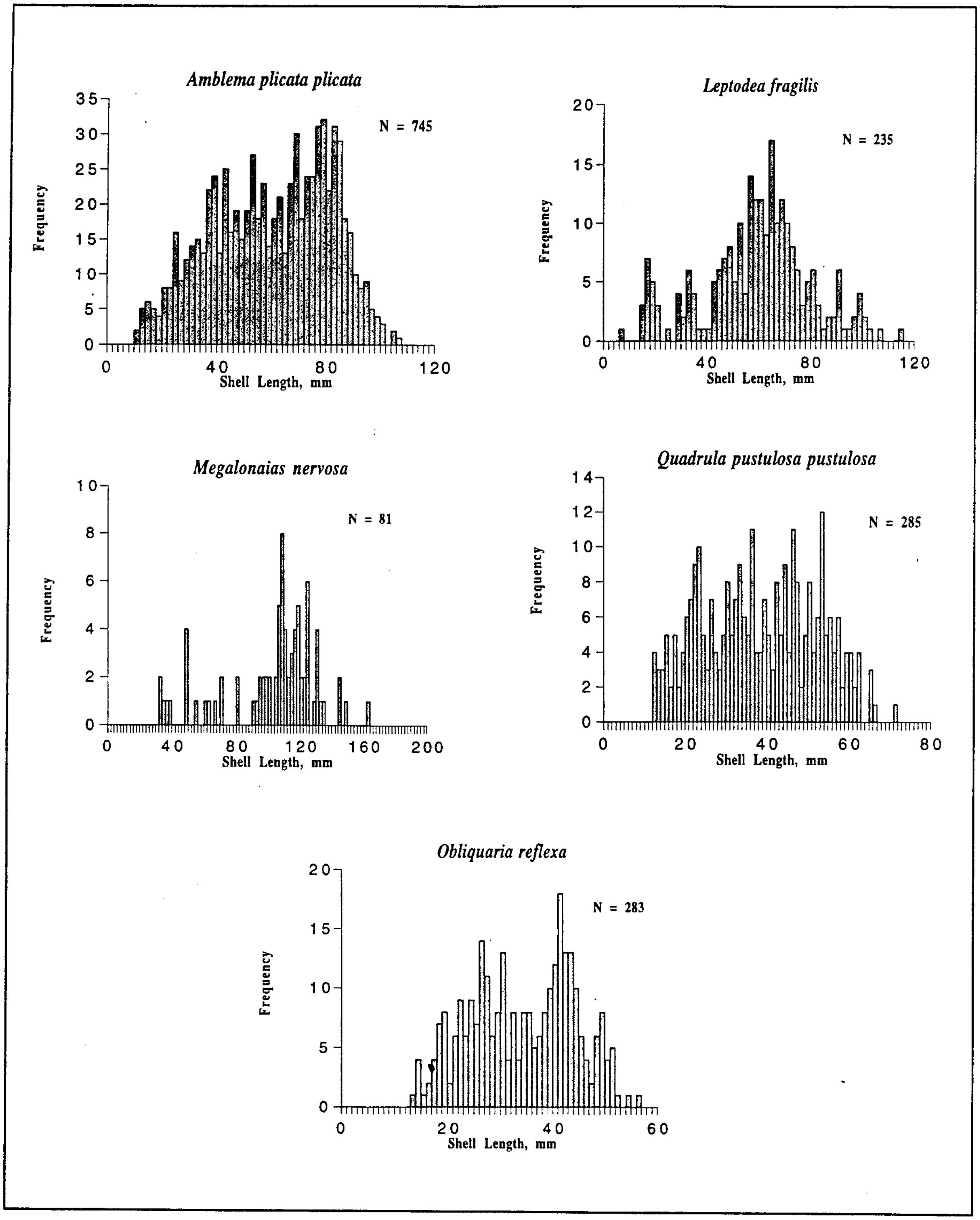

Figure 39. Evaluation of size demography in the UMR with samples composited from all five navigation pools, 1994

Table 1
Summary of Biological and Physical Studies Conducted in Navigation Traffic Effects Study, Upper Mississippi River, 1988-94 (This report describes studies conducted in 1994)

Pool	RM	Year						
		88	**89**	**90**	**91**	**92**	**93**	**94**
24	299.6	Qual	Qual		Qual		ND	Qual
		Quant	Quant		Quant		ND	Quant
					Growth			Growth
					Phys			
17	450.4	Qual		Qual		Qual		Qual
		Quant		Quant		Quant		Quant
				Growth				
				Phys				
14	504.8	Qual	Qual		Qual		ND	Qual
		Quant	Quant		Quant		ND	Quant
			Growth					
			Phys		Phys			
12	571.5		Qual	Qual		Qual		Qual
				Quant		Quant		Quant
				Growth				
				Phys				
10	635.2-MC	Qual	Qual		Qual		Qual	Qual
			Quant		Quant		Quant	Quant
			Growth					
			Phys		Phys			

Notes: Precise RM can differ in previous reports since exact location can vary slightly (0.1 to 0.4 miles) each year; Quant = Quantitative samples; Qual = Qualitative samples; Growth = Marked mussels were placed for analysis of rate of growth; Phys = Physical studies such as measures of water velocity and total suspended solids following passage of a commercial vessel; MC = Main Channel; ND = No data because of high water.

Table 2
Summary of Bivalve Collections Using Qualitative and Quantitative Methods in the UMR, 1988-94

Pool	RM	Year	No. of Quantitative Samples	No. of Qualitative Samples	No. of Bucket Samples
24	299.6	1988	10	18	--
		1989	60	42	--
		1990	--	--	--
		1991	60	24	--
		1992	--	12	10
		1993	--	--	--
		1994	60	24	--
17	450.4	1988	20	27	--
		1989	--	--	--
		1990	60	32	--
		1991	--	--	--
		1992	60	24	--
		1993	--	--	--
		1994	60	48	--
14	504.8	1988	20	27	--
		1989	60	59	--
		1990	--	--	--
		1991	60	48	--
		1992	60	36	--
		1993	--	--	--
		1994	60	48	--
12	571.5	1988	--	--	--
		1989	--	33	--
		1990	60	36	--
		1991	--	--	--
		1992	60	36	--
		1993	--	--	--
		1994	60	36	--

(Continued)

Note: High water in 1993 eliminated all sampling except in Pool 10. EC = East channel; MC = Main channel.

Table 2 (Concluded)					
Pool	RM	Year	No. of Quantitative Samples	No. of Qualitative Samples	No. of Bucket Samples
10	635.2	1988	--	43	--
		1989	40	14	--
		1990	--	--	--
		1991	60	48	--
		1992	--	24	40
		1993-MC	60	24	--
		1993-EC	60	60	--
		1994	60	--[1]	--

[1] No qualitative samples were collected in 1994. Instead a total of 43 separate samples were collected with a suction dredge at a nearshore site in the main channel, two sites in the turning basin of the east channel, and a single site at the reference site in the east channel. See Appendix C for data.

Table 3
Location of Sites Where Quantitative and Qualitative Samples Were Collected in UMR, 1994

River Mile	Subsite	Distance to Shore, ft	Depth, ft	Qualitative Samples	Quantitative Samples
23-24 Jul 94, Pool 24					
299.6	1-3	100	10-14	12	30
	4-6	220	17-20	12	30
25-26 Jul 94, Pool 17					
450.4	1-3	85	17-19	24	30
	4-6	140	19-21	24	30
27-28 Jul 94, Pool 14					
504.8	1-3	100	12	24	30
	4-6	275	14	24	30
29-30 Jul 94, Pool 12					
571.5	1-2	75	9-10	12	20
	3-4	140	12-14	12	20
	5-6	220	14-15	12	20
31 Jul - 1 Aug, Pool 10					
635.2	1-3	75	20-22	--[1]	30
	4-5	120	20-22	--[1]	30

[1] No qualitative samples were collected in 1994. Instead a total of 43 separate samples were collected with a suction dredge at a nearshore site in the main channel, two sites in the turning basin of the east channel, and a single site at the reference site in the east channel. See Appendix C for data.

Table 4
Freshwater Bivalves Collected Using Qualitative (Qual) and Quantitative (Quant) Techniques in Main and East Channel of Upper Mississippi River, July 1994

Species	Qual	Quant
Amblema plicata plicata (Say)	X	X
Actinonaias ligamentina (Lamarck)	X	X
Pyanpdpn grandis (Say)	X	X
Utterbackia imbecillis Say	X	X
Arcidens confragosus (Say)	X	X
Corbicula fluminea (Mueller)		X
Dreissena polymorpha (Pallas)	X	X
Ellipsaria lineolata (Rafinesque)	X	X
Elliptio dilatata (Rafinesque)	X	X
Fusconaia flava (Rafinesque)	X	X
Lasmigona complanata (Barnes)	X	X
Lampsilis higginsi (Lea)	X	X
Lampsilis cardium (Rafinesque)	X	X
Lampsilis teres (Rafinesque)	X	
Leptodea fragilis (Rafinesque)	X	X
Ligumia recta (Lamarck)	X	X
Megalonaias nervosa (Rafinesque)	X	X
Obliquaria reflexa Rafinesque	X	X
Obovaria olivaria (Rafinesque)	X	X
Potamilus alatus (Say)	X	X
Quadrula metanevra (Rafinesque)	X	X
Quadrula nodulata (Rafinesque)	X	x
Quadrula pustulosa pustulosa (I. Lea)	X	X
Quadrula quadrula (Rafinesque)	X	X
Strophitus undulatus (Say)	X	X
Truncilla donaciformis (I. Lea)	X	X
Truncilla truncata Rafinesque	X	X
Total individuals	2,559	3,108
Total species	26	26
Total samples	161	300

Table 5
Summary Statistics for Mean Unionid Densities by Subsite, Site, and River Mile, UMR, 1994

Site/Subsite	N	Mean	SE	F	Pr > F
River Mile 299.6, Pool 24					
NS-1	10	11.20[b]	3.20		
NS-2	10	30.80[a]	7.28		
NS-3	10	13.60[b]	4.59		
Total	30	18.5A[A]	3.37		
FS-1	10	13.60[b]	2.25		
FS-2	10	17.60[b]	3.64		
FS-3	10	10.40[b]	2.61		
Total	30	13.87[A]	1.70	3.15	0.0140
Between sites				1.53	0.2212
River Mile 405.4, Pool 17					
NS-1	10	94.40[a]	7.18		
NS-2	10	94.00[a]	7.26		
NS-3	10	56.00[b]	10.83		
Total	30	81.57[A]	5.84		
FS-1	10	14.80[c]	1.89		
FS-2	10	18.00[c]	3.28		
FS-3	10	32.00[c]	3.91		
Total	30	21.60[B]	2.23	31.12	0.0001
Between sites				91.66	0.0001
River Mile 504.8, Pool 14					
NS-1	10	75.60[a]	5.58		
NS-2	10	56.40[bc]	6.54		
NS-3	10	54.40[bc]	5.31		
Total	30	62.13[A]	3.70		
FS-1	10	60.80[abc]	6.22		
FS-2	10	48.00[c]	4.09		
FS-3	10	66.00[ab]	5.76		

(Continued)

Note: The two nonindigenous species, *C. fluminea* and *D. polymorpha*, have not been included. Means with the same letter (lower case for subsite and upper case for intersite comparisons) are not significantly different at the 0.05-level based on Duncan's Multiple Range Test.

Table 5 (Concluded)					
Site/Subsite	**N**	**Mean**	**SE**	**F**	**Pr > F**
River Mile 504.8, Pool 14 (Continued)					
Total	30	58.26^{A}	3.34	2.95	0.0201
Between sites				0.60	0.4410
River Mile 571.5, Pool 12					
NS-1	10	36.80^{ab}	2.44		
NS-2	10	31.30^{b}	3.03		
Total	20	34.00^{B}	2.00		
MS-1	10	24.80^{b}	2.72		
MS-2	10	28.40^{b}	3.74		
Total	20	26.60^{B}	2.29		
FS-1	10	47.60^{a}	6.46		
FS-2	10	36.40^{ab}	3.50		
Total	20	42.00^{A}	3.80	4.27	0.0024
Among sites				7.51	0.0013
River Mile 635.2, Pool 10, Main Channel					
NS-1	10	52.00^{ab}	8.20		
NS-2	10	35.20^{b}	5.09		
NS-3	10	38.40^{b}	5.50		
Total	30	41.87^{A}	3.82		
FS-1	10	40.80^{b}	6.74		
FS-2	10	44.40^{ab}	5.18		
FS-3	10	62.00^{a}	4.01		
Total	30	49.07^{A}	3.48	2.80	0.0254
Between sites				1.94	0.1687
Summary by River Mile (overall density)					
River Mile	**N**	**Mean**	**SE**	**F**	**Pr > F**
299.6	60	16.20^{d}	1.90		
450.4	60	51.53^{ab}	4.98		
Site/Subsite	**N**	**Mean**	**SE**	**F**	**Pr > F**
504.8	60	60.20^{a}	2.48		
571.5	60	34.20^{c}	1.79		
635.2	60	45.47^{b}	2.60		
Among sites				23.09	0.00

Table 6
Summary Statistics for Mean *D. polymorpha* Densities by Subsite, Site, and River Mile, UMR, 1994

Site/Subsite	N	Mean	SE	F	Pr > F
River Mile 299.6, Pool 24					
NS-1	10	0.00[a]	0.00		
NS-2	10	0.40[a]	0.40		
NS-3	10	0.40[a]	0.40		
Total	30	0.27[A]	0.19		
FS-1	10	0.00[a]	0.00		
FS-2	10	0.00[a]	0.00		
FS-3	10	0.80[a]	0.53		
Total	30	0.27[A]	0.19	1.96	0.3934
Between sites				0.00	1.0000
River Mile 405.4, Pool 17					
NS-1	10	8.40[a]	2.02		
NS-2	10	1.60[b]	0.88		
NS-3	10	1.60[b]	0.88		
Total	30	3.87[A]	0.97		
FS-1	10	0.00[b]	0.00		
FS-2	10	0.00[b]	0.00		
FS-3	10	0.40[b]	0.40		
Total	30	0.13[B]	0.13	10.73	0.0001
Between sites				14.59	0.0003
River Mile 504.8, Pool 14					
NS-1	10	14.80[a]	3.04		
NS-2	10	2.40[c]	0.88		
NS-3	10	2.40[c]	1.22		
Total	30	6.53[A]	1.54		
FS-1	10	12.80[ab]	3.20		
FS-2	10	4.80[bc]	1.55		
FS-3	10	12.00[ab]	4.84		

(Continued)

Note: The two nonindigenous species, *C. fluminea* and *D. polymorpha*, have not been included. Means with the same letter (lower case for subsite and upper case for intersite comparisons) are not significantly different at the 0.05-level based on Duncan's Multiple Range Test.

Table 6 (Concluded)

Site/Subsite	N	Mean	SE	F	Pr > F
River Mile 504.8, Pool 14 (Continued)					
Total	30	9.87[A]	2.05	3.98	0.0038
Between sites				1.70	0.1981
River Mile 571.5, Pool 12					
NS-1	10	2.00[a]	0.67		
NS-2	10	2.40[a]	1.07		
Total	20	2.20[A]	0.61		
MS-1	10	1.60[a]	0.88		
MS-2	10	2.00[a]	0.89		
Total	20	1.80[A]	0.61		
FS-1	10	2.40[a]	0.65		
FS-2	10	2.80[a]	1.20		
Total	20	2.60[A]	0.67	0.21	0.9569
Among sites				0.40	0.6717
River Mile 635.2, Pool 10, Main Channel					
NS-1	10	2.40[a]	1.36		
NS-2	10	1.60[a]	0.88		
NS-3	10	1.60[a]	0.88		
Total	30	1.87[A]	0.06		
FS-1	10	4.00[a]	1.33		
FS-2	10	1.60[a]	0.65		
FS-3	10	4.40[a]	1.63		
Total	30	3.33[A]	0.74	1.20	0.3235
Between sites				2.36	0.1320
Summary by River Mile (overall density)					
River Mile	**N**	**Mean**	**SE**	**F**	**Pr > F**
299.6	60	0.27[c]	0.13		
450.4	60	2.00[c]	0.54		
Site/Subsite	**N**	**Mean**	**SE**	**F**	**Pr > F**
504.8	60	8.20[b]	1.29		
571.5	60	2.20[c]	0.36		
635.2	60	2.60[c]	0.48		
Among sites				27.77	0.0001

Table 7
Number of Fresh Dead Unionidae (tissue present) in Quantitative Samples Collected at Five Locations in the UMR, 1994

Location	Subsite		
	1	2	3
RM 299.6			
Nearshore	0	0	1
Farshore	0	0	0
RM 450.4			
Nearshore	0	0	0
Farshore	0	0	0
RM 504.8			
Nearshore	0	0	0
Farshore	0	0	0
RM 571.5			
Nearshore	0	0	--
Midshore	0	0	--
Farshore	0	0	--
Main Channel			
Nearshore	0	0	0
Farshore	0	0	0

Table 8
Numbers of *Lampsilis higginsi* Taken in Qualitative and Quantitative Samples in the UMR, 1988-94

Year	Quantitative Samples			Qualitative Samples		
	Total Mussels	*L. higginsi*		Total Mussels	*L. higginsi*	
		Total	%		Total	%
Pool 24 (RM 299.6)						
1988	78	0	0.00	326	0	0.00
1989	1,143	0	0.00	648	0	0.00
1991	301	0	0.00	465	0	0.00
1992	107	0	0.00	184	0	0.00
1994	243	0	0.00	390	0	0.00
Pool 17 (RM 450.4)						
1988	1,176	0	0.00	567	1	0.18
1990	651	0	0.00	506	0	0.00
1992	954	0	0.00	402	0	0.00
1994	773	0	0.00	801	1	0.12
Pool 14 (RM 504.8)						
1988	253	1	0.40	734	8	1.09
1989	1,131	1	0.09	961	5	0.52
1991	1,247	6	0.49	815	6	0.74
1992	800	2	0.25	386	3	0.78
1994	903	4	0.44	789	6	0.76
Pool 12 (RM 571.5)						
1989	--	--	--	98	0	0.00
1990	408	5	1.22	518	5	0.98
1992	558	1	0.18	376	0	0.00
1994	509	0	0.00	579	0	0.00
Pool 10 (RM 635.2 - Main Channel)						
1988	845	2	0.24	699	12	1.72
1989	1,616	11	0.68	212	0	0.00
1991	861	2	0.23	690	4	0.58
1992	700	3	0.43	376	1	0.27
1993	905	4	0.11	404	1	0.25
1994	680	1	0.15	--	--	--

Appendix A
Freshwater Mussels Collected in the Upper Mississippi River, 1994, Using Quantitative Methods

Table A1
Percent Abundance of Native Bivalves Collected at a Nearshore and Farshore Site, Pool 24, RM 299.6, 1994

Species/Parameter	Nearshore				Farshore				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
T. truncata	21.43	41.56	70.59	44.60	23.53	22.73	30.77	25.00	36.21
O. reflexa	21.43	18.18	20.59	19.42	20.59	20.45	19.23	20.19	19.75
E. lineolata	21.43	14.29	0.00	12.23	8.82	13.64	11.54	11.54	11.93
L. fragilis	14.29	9.09	5.88	9.35	2.94	13.64	26.92	13.46	11.11
A. p. plicata	10.71	10.39	0.00	7.91	14.71	9.09	7.69	10.58	9.05
Q. p. pustulosa	7.14	2.60	0.00	2.88	5.88	2.27	0.00	2.88	2.88
T. donaciformis	0.00	1.30	2.94	1.44	5.88	0.00	0.00	1.92	1.65
Q. quadrula	0.00	2.60	0.00	1.44	0.00	0.00	0.00	0.00	0.82
O. olivaria	3.57	0.00	0.00	0.72	8.82	4.55	3.85	5.77	2.88
L. cardium	0.00	0.00	0.00	0.00	2.94	0.00	0.00	0.96	0.41
Q. nodulata	0.00	0.00	0.00	0.00	0.00	2.27	0.00	0.96	0.41
P. alatus	0.00	0.00	0.00	0.00	0.00	2.27	0.00	0.96	0.41
M. nervosa	0.00	0.00	0.00	0.00	0.00	4.55	0.00	1.92	0.82
L. complanata	0.00	0.00	0.00	0.00	2.94	0.00	0.00	0.96	0.41
L. recta	0.00	0.00	0.00	0.00	0.00	4.55	0.00	1.92	0.82
F. flava	0.00	0.00	0.00	0.00	2.94	0.00	0.00	0.96	0.41
Total individuals	28	77	34	139	34	44	26	104	243
Total species	7	8	4	9	11	11	6	15	16
% Individuals <30 mm	32.14	42.85	73.53	48.20	23.53	18.18	38.46	36.95	38.27
% Species <30 mm	57.14	75.00	75.00	77.78	27.27	18.18	50.00	20.67	43.75
Menhinick's Index	1.32	0.91	0.68	0.76	1.89	1.66	0.99	1.47	1.02
Diversity (H')	1.81	1.65	0.84	1.62	2.12	2.10	1.69	2.14	1.91
Evenness	1.14	0.76	0.67	0.69	1.00	0.96	1.06	0.79	0.68

Table A2
Percent Occurrence of Native Bivalves Collected at a Nearshore and Farshore Site, Pool 24, RM 299.6, 1994

Species/Parameter	Nearshore				Farshore				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
T. truncata	80.00	100.00	80.00	60.00	60.00	50.00	40.00	50.00	55.00
L. fragilis	70.00	90.00	50.00	43.33	10.00	30.00	60.00	33.33	38.33
O. reflexa	30.00	60.00	30.00	46.67	50.00	60.00	40.00	50.00	48.33
E. lineolata	10.00	60.00	70.00	36.67	30.00	30.00	20.00	26.67	31.67
A. p. plicata	50.00	40.00	20.00	20.00	30.00	40.00	10.00	26.67	23.33
O. olivaria	20.00	10.00	0.00	3.33	20.00	20.00	10.00	16.67	10.00
L. cardium	20.00	0.00	0.00	0.00	10.00	0.00	0.00	3.33	1.67
T. donaciformis	0.00	0.00	0.00	6.67	20.00	0.00	0.00	6.67	6.67
Q. p. pustulosa	30.00	20.00	10.00	6.67	20.00	10.00	0.00	10.00	8.33
M. nervosa	10.00	0.00	0.00	0.00	0.00	20.00	0.00	6.67	3.33
Q. nodulata	0.00	10.00	0.00	0.00	0.00	10.00	0.00	3.33	1.67
P. alatus	0.00	10.00	0.00	0.00	0.00	10.00	0.00	3.33	1.67
Q. quadrula	0.00	20.00	0.00	6.67	0.00	0.00	0.00	0.00	3.33
L. complanata	10.00	0.00	0.00	0.00	10.00	0.00	0.00	3.33	1.67
L. recta	0.00	20.00	0.00	0.00	0.00	20.00	0.00	6.67	3.33
F. flava	10.00	0.00	0.00	0.00	10.00	0.00	0.00	3.33	1.67
Total samples	10	10	10	30	10	10	10	30	60

Table A3
Percent Abundance of Freshwater Bivalves Collected from a Nearshore and Farshore Site, Pool 17, RM 450.4, 1994

Species/Parameter	Nearshore				Farshore				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
T. truncata	25.00	29.36	19.29	25.37	8.11	22.22	27.50	21.60	24.58
E. lineolata	20.34	22.55	25.00	22.26	10.81	20.00	18.75	17.28	21.22
Q. p. pustulosa	15.25	13.62	16.43	14.89	27.03	11.11	12.50	15.43	15.01
A. p. plicata	16.10	10.64	12.14	13.09	18.92	15.56	13.75	15.43	13.58
O. olivaria	0.85	0.85	1.43	0.98	5.41	6.67	10.00	8.02	2.46
O. reflexa	8.05	6.38	5.00	6.71	8.11	6.67	2.50	4.94	6.34
Q. metanevra	2.54	3.83	4.29	3.44	8.11	4.44	1.25	3.70	3.49
L. fragilis	1.69	2.55	7.86	3.44	0.00	6.67	3.75	3.70	3.49
L. complanata	0.42	0.00	0.00	0.16	2.70	2.22	3.75	3.09	0.78
F. flava	0.85	0.00	1.43	0.65	10.81	0.00	1.25	3.09	1.16
A. ligamentina	1.69	1.28	1.43	1.47	0.00	0.00	3.75	1.85	1.55
L. recta	0.00	0.00	0.00	0.00	0.00	2.22	1.25	1.23	0.26
M. nervosa	4.66	3.40	2.14	3.60	0.00	2.22	0.00	0.62	2.98
L. cardium	0.85	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.26
T. donaciformis	1.27	2.98	0.71	1.80	0.00	0.00	0.00	0.00	1.42
L. higginsi	0.00	0.00	0.71	0.16	0.00	0.00	0.00	0.00	0.13
Q. quadrula	0.42	2.13	0.71	1.15	0.00	0.00	0.00	0.00	0.91
A. confragosus	0.00	0.43	1.43	0.49	0.00	0.00	0.00	0.00	0.39
Total individuals	236	235	140	611	37	45	80	162	773
Total species	15	13	15	17	9	11	12	12	18
% Individuals <30 mm	35.17	29.78	24.28	30.61	8.11	37.78	30.37	27.32	29.92
% Species <30 mm	46.67	38.46	40	41.18	22.22	45.45	41.67	38.46	44.44
Menhinik's Index	0.98	0.84	1.27	0.69	1.48	1.64	0.94	0.44	0.65
Diversity (H')	2.05	2.02	2.13	2.09	2.02	2.12	2.16	1.96	2.15
Evenness	0.77	0.73	0.78	0.73	1.01	0.97	0.85	0.78	0.72

Table A4
Percent Occurrence of Freshwater Bivalves Collected from a Nearshore and Farshore Site, Pool 17, RM 450.4, 1994

Species/Parameter	Nearshore				Farshore				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
A. p. plicata	90.00	100.00	80.00	90.00	60.00	60.00	70.00	63.33	76.67
Q. p. pustulosa	100.00	90.00	80.00	90.00	60.00	50.00	60.00	56.67	73.33
T. truncata	100.00	100.00	70.00	90.00	20.00	60.00	90.00	56.67	73.33
E. lineolata	90.00	100.00	80.00	90.00	40.00	60.00	60.00	53.33	71.67
O. reflexa	100.00	60.00	50.00	70.00	30.00	10.00	20.00	20.00	45.00
Q. metanevra	50.00	50.00	40.00	46.67	30.00	20.00	10.00	20.00	33.33
L. fragilis	30.00	60.00	50.00	46.67	0.00	30.00	20.00	16.67	31.67
M. nervosa	70.00	70.00	20.00	53.33	0.00	10.00	0.00	3.33	28.33
O. olivaria	20.00	20.00	20.00	20.00	20.00	30.00	60.00	36.67	28.33
T. donaciformis	30.00	60.00	10.00	33.33	0.00	0.00	0.00	0.00	16.67
A. ligamentina	30.00	30.00	20.00	26.67	0.00	0.00	20.00	6.67	16.67
F. flava	20.00	0.00	10.00	10.00	40.00	0.00	10.00	16.67	13.33
Q. quadrula	10.00	50.00	10.00	23.33	0.00	0.00	0.00	0.00	11.67
L. complanata	10.00	0.00	0.00	3.33	10.00	10.00	30.00	16.67	10.00
A. confragosus	0.00	10.00	20.00	10.00	0.00	0.00	0.00	0.00	5.00
L. recta	0.00	0.00	0.00	0.00	0.00	10.00	10.00	6.67	3.33
L. cardium	20.00	0.00	0.00	6.67	0.00	0.00	0.00	0.00	3.33
L. higginsi	0.00	0.00	10.00	3.33	0.00	0.00	0.00	0.00	1.67
Total samples	10	10	10	30	10	10	10	30	60

Table A5
Percent Abundance of Freshwater Mussels Collected Using Quantitative Methods in Pool 14, RM 504.8, July 1994

Species/Parameter	Nearshore				Farshore				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
T. truncata	23.81	22.70	22.06	22.96	26.97	27.50	27.88	27.46	25.14
A. p. plicata	20.63	19.15	19.85	19.96	9.87	22.50	16.36	15.79	17.94
Q. pustulosa	10.58	21.28	13.97	14.81	16.45	15.83	16.36	16.25	15.50
O. reflexa	11.11	9.93	19.12	13.09	11.84	10.00	10.30	10.76	11.96
L. fragilis	10.05	3.55	7.35	7.30	9.21	2.50	9.70	7.55	7.42
Q. quadrula	4.23	7.80	5.88	5.79	5.92	6.67	5.45	5.95	5.87
E. lineolata	6.88	9.22	2.94	6.44	4.61	5.00	3.64	4.35	5.43
T. donaciformis	1.06	0.71	1.47	1.07	3.29	1.67	2.42	2.52	1.77
L. cardium	1.59	2.13	2.21	1.93	0.66	1.67	2.42	1.60	1.77
M. nervosa	2.65	0.00	0.74	1.29	3.29	1.67	1.82	2.29	1.77
F. flava	1.59	0.71	1.47	1.29	2.63	1.67	1.21	1.83	1.55
L. recta	2.12	0.00	0.00	0.86	0.66	0.83	0.00	0.46	0.66
O. olivaria	0.00	0.71	0.00	0.21	1.32	0.83	1.21	1.14	0.66
P. alatus	1.06	0.00	0.00	0.43	1.32	0.00	1.21	0.92	0.66
A. confragosus	0.53	1.42	1.47	1.07	0.00	0.00	0.00	0.00	0.55
Q. nodulata	1.06	0.00	0.74	0.64	0.00	0.83	0.00	0.23	0.44
L. higginsi	0.53	0.00	0.00	0.21	1.32	0.83	0.00	0.69	0.44
U. imbecillis	0.53	0.00	0.74	043	0.66	0.00	0.00	0.23	033
Q. metanevra	0.00	0.71	0.00	0.21	0.00	0.00	0.00	0.00	0.11
Total individuals	189	141	136	466	152	120	165	437	903
Total species	17	13	14	19	15	15	13	17	20
% Individuals <30 mm	29.63	43.53	32.39	33.04	42.39	41.67	44.39	33.41	32.22
% Species <30 mm	52.94	64.28	40.00	52.63	41.17	50.00	66.67	47.06	50.00
Menhinik's Index	1.23	1.09	1.20	0.88	1.22	1.37	1.01	0.81	0.66
Diversity (H')	2.23	2.03	2.09	2.19	2.22	2.07	2.10	2.18	2.20
Evenness	0.75	0.83	0.81	0.75	0.76	0.74	0.77	0.73	0.73

Table A6
Percent Occurrence of Freshwater Mussels Collected Using Quantitative Methods in Pool 14, RM 504.8, July 1994

Species/Parameter	Nearshore				Farshore				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
T. truncata	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
A. p. plicata	100.00	100.00	100.00	100.00	90.00	100.00	100.00	96.67	98.33
Q. p. pustulosa	100.00	100.00	80.00	93.33	100.00	80.00	100.00	93.33	93.33
O. reflexa	90.00	70.00	90.00	83.33	80.00	80.00	80.00	80.00	81.67
Q. quadrula	60.00	70.00	60.00	63.33	80.00	50.00	60.00	63.33	63.33
E. lineolata	70.00	90.00	40.00	66.67	50.00	60.00	40.00	50.00	58.33
L. fragilis	80.00	40.00	40.00	53.33	50.00	30.00	70.00	50.00	51.67
T. donaciformis	20.00	10.00	20.00	16.67	40.00	20.00	40.00	33.33	25.00
F. flava	30.00	10.00	20.00	20.00	40.00	10.00	20.00	23.33	21.67
M. nervosa	40.00	0.00	10.00	16.67	40.00	20.00	30.00	30.00	23.33
L. cardium	30.00	20.00	20.00	23.33	10.00	20.00	30.00	20.00	21.67
P. alatus	20.00	0.00	0.00	6.67	10.00	0.00	20.00	10.00	8.33
A. confragosus	10.00	20.00	20.00	16.67	0.00	0.00	0.00	0.00	8.33
L. higginsi	10.00	0.00	0.00	3.33	20.00	10.00	0.00	10.00	6.67
L. recta	20.00	0.00	0.00	6.67	10.00	10.00	0.00	6.67	6.67
Q. nodulata	20.00	0.00	10.00	10.00	0.00	10.00	0.00	3.33	6.67
O. olivaria	0.00	10.00	0.00	3.33	20.00	0.00	0.00	6.67	5.00
U. imbecillis	10.00	0.00	10.00	6.67	10.00	0.00	0.00	3.33	5.00
Q. metanevra	0.00	10.00	0.00	3.33	0.00	0.00	0.00	0.00	1.67
Total samples	10	10	10	30	10	10	10	30	60

Table A7
Percent Abundance of Freshwater Bivalves Collected at Nearshore, Midshore, and Farshore Sites in Pool 12, RM 571.5, July 1994

Species/Parameter	Nearshore			Midshore			Farshore			Grand Total
	Subsite 1	Subsite 2	Total	Subsite 1	Subsite 2	Total	Subsite 1	Subsite 2	Total	
A. p. plicata	35.87	19.23	28.24	24.19	25.35	24.81	18.49	21.59	20.00	23.98
T. truncata	20.65	23.08	21.76	16.13	23.94	20.30	30.25	19.32	25.24	22.81
L. fragilis	6.52	12.82	9.41	14.52	18.31	16.54	7.56	11.36	9.52	11.31
O. reflexa	8.70	14.10	11.18	14.52	2.82	8.27	10.92	12.50	11.43	10.53
Q. quadrula	6.52	8.97	7.65	4.84	5.63	5.26	5.04	5.68	5.71	6.24
E. lineolata	0.00	0.00	0.00	4.84	1.41	3.01	8.40	6.82	7.62	3.90
M. nervosa	3.26	0.00	1.76	3.23	4.23	3.76	5.04	5.68	5.24	3.70
Q. p. pustulosa	3.26	1.28	2.35	4.84	0.00	2.26	4.20	3.41	3.81	2.92
L. cardium	1.09	2.56	1.76	3.23	5.63	4.51	1.68	3.41	2.38	2.73
F. flava	3.26	5.13	4.12	1.61	1.41	1.50	3.36	1.14	2.38	2.73
T. donaciformis	4.35	8.97	6.47	0.00	0.00	0.00	0.84	1.14	0.95	2.53
L. recta	1.09	3.85	2.35	6.45	0.00	3.01	0.00	0.00	0.00	1.56
U. imbecillis	1.09	0.00	0.59	0.00	7.04	3.76	0.84	2.27	1.43	1.75
P. alatus	1.09	0.00	0.59	0.00	2.82	1.50	0.84	3.41	1.90	1.36
O. olivaria	1.09	0.00	0.59	0.00	0.00	0.00	2.52	0.00	1.43	0.78
L. complanata	1.09	0.00	0.59	0.00	0.00	0.00	0.00	1.14	0.48	0.39
A. ligamentina	0.00	0.00	0.00	1.61	0.00	0.75	0.00	0.00	0.00	0.19
Q. nodulata	1.09	0.00	0.59	0.00	0.00	0.00	0.00	0.00	0.00	0.19
A. confragosus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.14	0.48	0.19
Total individuals	92	78	170	62	71	133	119	88	210	509
Total species	16	10	16	12	11	14	14	15	16	20
% Individuals <30 mm	62.82	19.35	54.71	19.35	30.98	25.56	16.81	12.09	14.76	30.79
% Species <30 mm	80.00	6.50	56.25	50.00	45.45	50.00	42.85	53.33	62.50	60.00
Menhinick's Index	1.67	1.13	1.23	1.52	1.31	1.22	1.28	1.57	1.10	0.88
Diversity (H')	2.08	2.05	2.13	2.17	1.98	2.18	2.15	2.29	2.25	2.28
Evenness	0.63	0.93	0.72	0.89	0.82	0.76	0.73	0.83	0.74	0.69

Table A8
Percent Occurrence of Mussel Species Collected at Nearshore, Midshore, and Farshore Sites, Pool 12, RM 571.5, 1994

Species/Parameter	Nearshore			Midshore			Farshore			Grand Total
	Subsite 1	Subsite 2	Total	Subsite 1	Subsite 2	Total	Subsite 1	Subsite 2	Total	
A. p. plicata	100.00	80.00	90.00	80.00	90.00	85.00	90.00	80.00	85.00	85.00
T. truncata	80.00	90.00	85.00	40.00	90.00	65.00	80.00	80.00	80.00	76.67
L. fragilis	30.00	80.00	55.00	60.00	80.00	70.00	70.00	80.00	75.00	65.00
O. reflexa	60.00	70.00	65.00	80.00	20.00	50.00	70.00	60.00	65.00	60.00
Q. quadrula	50.00	60.00	55.00	30.00	30.00	30.00	50.00	50.00	50.00	43.33
E. lineolata	0.00	0.00	0.00	20.00	10.00	15.00	50.00	40.00	45.00	20.00
M. nervosa	30.00	0.00	15.00	20.00	20.00	20.00	50.00	50.00	50.00	28.33
Q. p. pustulosa	30.00	10.00	20.00	30.00	0.00	15.00	50.00	20.00	35.00	23.33
L. cardium	10.00	20.00	15.00	20.00	40.00	30.00	20.00	30.00	25.00	23.33
F. flava	20.00	40.00	30.00	10.00	10.00	10.00	40.00	10.00	25.00	21.67
T. donaciformis	30.00	70.00	50.00	0.00	0.00	0.00	10.00	10.00	10.00	20.00
L. recta	10.00	30.00	20.00	30.00	0.00	15.00	0.00	0.00	0.00	11.67
U. imbecillis	0.00	0.00	5.00	0.00	20.00	10.00	10.00	20.00	15.00	10.00
P. alatus	10.00	0.00	5.00	0.00	20.00	10.00	10.00	30.00	20.00	11.67
O. olivaria	10.00	0.00	5.00	0.00	0.00	0.00	30.00	0.00	15.00	6.67
L. complanata	10.00	0.00	5.00	0.00	0.00	0.00	0.00	10.00	5.00	3.33
A. ligamentina	0.00	0.00	0.00	10.00	0.00	5.00	0.00	0.00	0.00	1.67
Q. nodulata	10.00	0.00	5.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67
A. confragosus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	5.00	1.67
Total sites	10	10	20	10	10	20	10	10	20	60

Table A9
Percent Abundance of Native Mussels Collected at a Nearshore and Farshore Site, Pool 10, RM 635.2, Main Channel, July 1994

Species/Parameter	Nearshore				Farshore				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
A. p. plicata	51.54	48.28	42.71	48.08	44.12	43.24	58.06	49.73	48.97
T. truncata	17.69	22.99	20.83	20.19	20.59	23.42	16.13	19.57	19.85
L. fragilis	5.38	6.90	10.42	7.37	8.82	8.11	10.32	9.24	8.38
O. reflexa	1.54	3.45	4.17	2.88	2.94	4.50	4.52	4.08	3.53
Q. quadrula	3.85	2.30	1.04	2.56	4.90	4.50	3.23	4.08	3.38
F. flava	3.08	3.45	5.21	3.85	3.92	3.60	1.29	2.72	3.24
M. nervosa	4.62	1.15	3.13	3.21	5.88	0.90	1.94	2.72	2.94
T. donaciformis	1.54	4.60	1.04	2.24	2.94	3.60	0.00	1.90	2.06
L. cardium	0.77	1.15	1.04	0.96	0.98	1.80	0.65	1.09	1.03
P. grandis	0.77	2.30	2.08	1.60	0.00	0.00	1.29	0.54	1.03
Q. p. pustulosa	2.31	1.15	1.04	1.60	1.96	0.00	0.00	0.54	1.03
P. alatus	1.54	1.15	1.04	1.28	0.00	0.90	0.65	0.54	0.88
E. dilitata	0.77	0.00	2.08	0.96	0.98	1.80	0.00	0.82	0.88
L. recta	0.00	0.00	2.08	0.64	0.98	0.90	1.29	1.09	0.88
S. undulatus	2.31	1.15	0.00	1.28	0.00	0.00	0.65	0.27	0.74
Q. metanevra	0.00	0.00	0.00	0.00	0.00	2.70	0.00	0.82	0.44
E. lineolata	0.77	0.00	1.04	0.64	0.00	0.00	0.00	0.00	0.29
L. teres	0.00	0.00	1.04	0.00	0.00	0.00	0.00	0.00	0.00
A. corpulenta	0.77	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.15
U. imbecillis	0.77	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.15
L. higginsi	0.00	0.00	0.00	0.00	0.98	0.00	0.00	0.27	0.15
Total individuals	130	87	96	312	102	111	155	368	680
Total species	17	13	15	18	13	13	12	17	20
% Individuals <30 mm	13.07	12.64	14.74	13.46	12.74	17.12	8.39	12.23	12.79
% Species <30 mm	47.06	23.08	26.67	44.44	53.85	38.46	25	47.06	45
Menhinik's Index	1.49	1.39	1.54	1.01	1.29	1.23	0.96	0.89	0.77
Diversity (H')	1.77	1.68	1.86	1.82	1.81	1.79	1.44	1.71	1.78
Evenness	0.48	0.56	0.58	0.49	0.60	0.60	0.52	0.52	0.50

Table A10
Percent Occurrence of Native Mussels Collected at a Nearshore and Farshore Site in Pool 10, Main Channel, RM 635.2, July 1994

Species/Parameter	Nearshore				Farshore				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
A. p. plicata	100.00	100.00	90.00	96.67	90.00	100.00	100.00	96.67	96.67
T. truncata	90.00	70.00	90.00	83.33	100.00	70.00	90.00	86.67	85.00
L. fragilis	60.00	40.00	60.00	53.33	50.00	60.00	90.00	66.67	60.00
O. reflexa	10.00	30.00	30.00	23.33	30.00	50.00	50.00	43.33	33.33
Q. quadrula	30.00	20.00	10.00	20.00	40.00	50.00	40.00	43.33	31.67
F. flava	40.00	20.00	30.00	30.00	40.00	40.00	10.00	30.00	30.00
M. nervosa	40.00	10.00	30.00	26.67	30.00	10.00	20.00	20.00	23.33
T. donaciformis	20.00	30.00	10.00	20.00	30.00	40.00	0.00	23.33	21.67
L. cardium	10.00	10.00	10.00	10.00	10.00	20.00	10.00	13.33	11.67
P. grandis	10.00	20.00	20.00	16.67	0.00	0.00	20.00	6.67	11.67
Q. p. pustulosa	30.00	10.00	10.00	16.67	20.00	0.00	0.00	6.67	11.67
P. alatus	20.00	10.00	10.00	13.33	0.00	10.00	10.00	6.67	10.00
E. dilitata	10.00	0.00	10.00	6.67	10.00	10.00	0.00	6.67	6.67
L. recta	0.00	0.00	20.00	6.67	10.00	10.00	20.00	13.33	10.00
S. undulatus	20.00	10.00	0.00	10.00	0.00	0.00	10.00	3.33	6.67
Q. metanevra	0.00	0.00	0.00	0.00	0.00	30.00	0.00	10.00	5.00
E. lineolata	10.00	0.00	10.00	6.67	0.00	0.00	0.00	0.00	3.33
L. teres	0.00	0.00	10.00	3.33	0.00	0.00	0.00	0.00	1.67
A. corpulenta	10.00	0.00	0.00	3.33	0.00	0.00	0.00	0.00	1.67
U. imbecillis	10.00	0.00	0.00	3.33	0.00	0.00	0.00	0.00	1.67
L. higginsi	0.00	0.00	0.00	0.00	10.00	0.00	0.00	3.33	1.67
Total samples	10	10	10	30	10	10	10	30	60

Table A11
Percent Abundance for Native Freshwater Mussels Collected in the Turning Basin and a Reference Site Located Downriver, East Channel of the UMR, Pool 10, 1994

Species/Parameter	Turning Basin				Reference Site				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
A. p. plicata	55.56	60	40	55.17	42.77	35.46	37.2	38.64	40.45
T. truncata	0	0	10	1.72	14.46	18.44	14.63	15.71	14.18
L. fragilis	5.56	13.33	10	10.34	10.84	8.51	4.88	8.07	8.32
O. reflexa	16.67	13.33	20	15.52	3.01	8.51	7.32	6.16	7.18
F. flava	5.56	13.33	0	8.62	4.82	6.38	4.88	5.31	5.67
Q. p. pustulosa	0	0	0	0	2.41	5.67	6.10	4.67	4.16
M. nervosa	0	0	0	0	4.22	2.84	4.27	3.82	3.40
U. imbecillis	0	0	0	0	4.82	2.84	2.44	3.40	3.02
L. recta	0	0	0	0	3.61	1.42	3.66	2.97	2.65
Q. quadrula	5.56	0	10	3.45	3.61	1.42	2.44	2.55	2.65
T. donaciformis	0	0	0	0	1.81	2.13	4.27	2.76	2.46
L. cardium	0	0	0	0	1.81	2.13	1.83	1.91	1.70
P. alatus	5.56	0	0	1.72	0.60	1.42	0.61	0.85	0.95
Q. nodulata	0	0	10	1.72	0	0.71	0.61	0.42	0.57
E. dilitata	0	0	0	0	0.60	0	1.22	0.64	0.57
E. lineolata	0	0	0	0	0.60	0	1.22	0.64	0.57
S. undulatus	0	0	0	0	0	0.71	0.61	0.42	0.38
L. higginsi	0	0	0	0	0	0	1.22	0.42	0.38
L. leptodon	5.56	0	0	1.72	0	0.71	0	0.21	0.38
Q. metanevra	0	0	0	0	0	0.71	0	0.21	0.19
A. confragosus	0	0	0	0	0	0	0.61	0.21	0.19
Total Individuals	18	30	10	58	166	141	164	471	529
Total species	7	4	6	9	15	17	19	21	21
% Individuals <30 mm	22.22	26.67	50	29.31	12.65	29.78	23.78	21.65	22.49
% Species <30 mm	42.85	50	83.3	66.67	40	41.18	57.89	57.14	57.14
Menhenick's Index	1.65	0.73	1.90	1.18	1.16	1.43	1.48	0.97	0.91
Diversity (H')	1.43	1.11	1.61	1.46	1.98	2.12	2.23	2.16	2.13
Evenness	0.69	0.76	1.36	0.59	0.56	0.62	0.56	0.55	0.53

Table A12
Percent Occurrence for Native Freshwater Mussels Collected in the Turning Basin and a Reference Site Located Downriver, East Channel of the UMR, Pool 10, 1994

Species/Parameter	Turning Basin				Reference Site				Grand Total
	Subsite 1	Subsite 2	Subsite 3	Total	Subsite 1	Subsite 2	Subsite 3	Total	
A. p. plicata	50.00	80.00	30.00	53.33	100.00	100.00	100.00	100.00	76.67
T. truncata	0.00	0.00	10.00	3.33	90.00	100.00	90.00	93.33	48.33
L. fragilis	10.00	30.00	10.00	16.67	70.00	70.00	50.00	63.33	40.00
O. reflexa	30.00	40.00	10.00	26.67	50.00	70.00	60.00	60.00	43.33
F. flave	10.00	30.00	0.00	13.33	60.00	40.00	60.00	53.33	33.33
Q. p. pustulosa	0.00	0.00	0.00	0.00	40.00	60.00	90.00	63.33	31.67
M. nervosa	0.00	0.00	0.00	0.00	40.00	20.00	40.00	33.33	16.67
U. imbecillis	0.00	0.00	0.00	0.00	60.00	30.00	40.00	43.33	21.67
L. recta	0.00	0.00	0.00	0.00	50.00	20.00	40.00	36.67	18.33
Q. quadrula	10.00	0.00	10.00	6.67	40.00	20.00	30.00	30.00	18.33
T. donaciformis	0.00	0.00	0.00	0.00	30.00	20.00	50.00	33.33	16.67
L. cardium	0.00	0.00	0.00	0.00	30.00	20.00	20.00	23.33	11.67
P. alatus	10.00	0.00	0.00	3.33	10.00	20.00	10.00	13.33	8.33
Q. nodulata	0.00	0.00	10.00	3.33	0.00	10.00	10.00	6.67	5.00
E. dilitata	0.00	0.00	0.00	0.00	10.00	0.00	20.00	10.00	5.00
E. lineolata	0.00	0.00	0.00	0.00	10.00	0.00	20.00	10.00	5.00
S. undulatus	0.00	0.00	0.00	0.00	0.00	10.00	10.00	6.67	3.33
L. higginsi	0.00	0.00	0.00	0.00	0.00	0.00	20.00	6.67	3.33
L. leptodon	10.00	0.00	0.00	3.33	0.00	10.00	0.00	3.33	3.33
Q. metanevra	0.00	0.00	0.00	0.00	0.00	10.00	0.00	3.33	1.67
A. confragosus	0.00	0.00	0.00	0.00	0.00	0.00	10.00	3.33	1.67
Total samples	10	10	10	30	10	10	10	30	60

Appendix B
Freshwater Mussels Collected in the Upper Mississippi River, 1994, Using Qualitative Methods

Table B1
Percent Abundance of Freshwater Mussels Collected Using Qualitative Methods, Upper Mississippi River, July 1994

Species	Pool 24 RM 299.6	Pool 17 RM 450.4	Pool 14 RM 504.8	Pool 12 RM 571.5	Total
A. p.plicata	22.31	17.35	33.33	35.75	27.20
E. lineolata	16.67	25.09	3.93	1.90	12.04
Q. p. pustulosa	1.79	17.98	12.93	3.97	10.79
T. truncata	9.74	7.12	12.17	10.19	9.77
L. fragilis	25.38	3.87	5.20	9.67	8.87
O. reflexa	8.97	2.75	8.75	5.35	6.14
Q. quadrula	1.03	4.74	5.70	10.54	5.78
M. nervosa	3.85	5.99	2.28	5.87	4.49
F. flava	0.51	2.62	4.82	3.80	3.24
L. cardium	1.28	1.37	2.66	3.80	2.31
O. olivaria	6.67	1.50	0.13	0.69	1.68
L. recta	0.77	0.37	2.28	3.11	1.64
Q. metanevra	0.26	2.62	0.38	0.69	1.13
A. ligamentina	0.00	3.12	0.00	0.17	1.02
L. complanata	0.00	1.25	0.13	1.55	0.78
P. alatus	0.00	0.12	1.27	1.21	0.70
A. confragosus	0.26	0.87	0.51	0.52	0.59
E. dilatata	0.00	0.00	1.65	0.00	0.51
Q. nodulata	0.00	0.25	0.89	0.17	0.39
L. higginsi	0.00	0.12	0.76	0.00	0.27
P. grandis	0.00	0.12	0.25	0.52	0.23
S. undulatus	0.00	0.75	0.00	0.00	0.23
U. imbecillis	0.00	0.00	0.00	0.35	0.08
L. teres	0.51	0.00	0.00	0.00	0.08
T. donaciformis	0.00	0.00	0.00	0.17	0.04
Total individuals	390	801	789	579	2,559

Table B2
Percent Occurrence of Freshwater Mussels Collected Using Qualitative Methods, Upper Mississippi River, July 1994

Species	Pool 24 RM 299.6	Pool 17 RM 450.5	Pool 14 RM 504.8	Pool 12 RM 571.5	Total
A. p. plicata	82.76	91.67	93.75	91.67	90.68
T. truncata	62.07	68.75	81.25	72.22	72.05
Q. p. pustulosa	24.14	91.67	81.25	50.00	67.08
E. lineolata	79.31	89.58	35.42	27.78	57.76
L. fragilis	79.31	35.42	47.92	63.89	53.42
O. reflexa	48.28	37.50	72.92	50.00	52.80
Q. quadrula	13.79	47.92	52.08	75.00	49.07
M. nervosa	27.59	56.25	25.00	58.33	42.24
F. flava	6.90	27.08	54.17	41.67	34.78
L. cardium	13.79	22.92	37.50	50.00	31.68
L. recta	10.34	6.25	29.17	38.89	21.12
O. olivaria	58.62	22.92	2.08	5.56	19.25
Q. metanevra	3.45	33.33	6.25	8.33	14.29
A. ligamentina	0.00	37.50	0.00	2.78	11.80
L. complanata	0.00	18.75	2.08	16.67	9.94
P. alatus	0.00	2.08	18.75	13.89	9.32
A. confragosus	3.45	14.58	8.33	8.33	9.32
Q. nodulata	0.00	4.17	12.50	2.78	5.59
E. dilatata	0.00	0.00	14.58	0.00	4.35
L. higginsi	0.00	2.08	10.42	0.00	3.73
P. grandis	0.00	2.08	4.17	5.56	3.11
S. undulatus	0.00	10.42	0.00	0.00	3.11
L. teres	6.90	0.00	0.00	0.00	1.24
U. imbecillis	0.00	0.00	0.00	5.56	1.24
T. donaciformis	0.00	0.00	0.00	2.78	0.62
Total samples	29	48	48	36	161

Appendix C
Percent Abundance and Frequency of Occurrence of Native Freshwater Mussels Collected With a Suction Dredge at Four Sites in Pool 10 of the Upper Mississippi River (UMR), 1994

Table C1
Percent Abundance of Species Collected With a Suction Dredge in Pool 10 of the UMR near RM 635.2, July 1994

Species	Main Channel Nearshore	East Channel Reference Site	East Channel Turning Basin No. 1	East Channel Turning Basin No. 2	Grand Total
A. p. plicata	50.93	39.26	31.71	41.73	42.13
L. fragilis	11.11	15.95	24.39	16.55	15.74
T. truncata	22.22	15.95	7.32	7.91	14.19
F. flava	2.78	7.98	19.51	4.32	6.65
O. reflexa	5.56	1.84	2.44	13.67	6.43
Q. quadrula	0.93	1.23	7.32	5.76	3.10
Q. pustulosa	0.00	4.29	0.00	2.88	2.44
M. nervosa	0.00	4.91	0.00	0.72	2.00
T. donaciformis	1.85	2.45	0.00	2.16	2.00
P. alatus	0.93	0.00	4.88	2.16	1.33
P. grandis	1.85	1.84	0.00	0.00	1.11
E. dilatata	0.93	1.23	0.00	0.00	0.67
L. cardium	0.00	0.00	2.44	0.72	0.44
O. olivaria	0.93	0.61	0.00	0.00	0.44
L. teres	0.00	0.61	0.00	0.00	0.22
L. recta	0.00	0.61	0.00	0.00	0.22
U. imbecillis	0.00	0.61	0.00	0.00	0.22
A. ligamentina	0.00	0.61	0.00	0.00	0.22
Q. nodulata	0.00	0.00	0.00	0.72	0.22
A. confragosus	0.00	0.00	0.00	0.72	0.22
Total individuals	108	163	41	139	451
Total species	11	16	8	13	20
% Individuals <30 mm	13.89	17.79	51.21	41.01	27.05
% Species <30 mm	45.45	37.50	75.00	69.23	60.00
Menhinik's Index	1.06	1.25	1.25	1.10	0.94
Diversity (H')	1.50	1.94	1.74	1.84	1.91
Evenness	0.61	0.62	0.89	0.64	0.57

Table C2
Percent Occurrence of Species Collected With a Suction Dredge in Pool 10 of the UMR near RM 635.2, July 1994

Species	Main Channel Nearshore	East Channel Reference Site	East Channel Turning Basin No. 1	East Channel Turning Basin No. 2	Grand Total
A. p. plicata	90.00	90.00	80.00	100.00	90.70
T. truncata	80.00	80.00	30.00	53.85	60.47
L. fragilis	50.00	100.00	40.00	46.15	58.14
F. flava	30.00	60.00	60.00	46.15	48.84
O. reflexa	40.00	30.00	10.00	84.62	44.19
Q. quadrula	10.00	20.00	30.00	53.85	30.23
T. donaciformis	20.00	40.00	0.00	23.08	20.93
Q. pustulosa	0.00	60.00	0.00	23.08	20.93
M. nervosa	0.00	50.00	0.00	7.69	13.95
P. grandis	20.00	30.00	0.00	0.00	11.63
P. alatus	10.00	0.00	20.00	15.38	11.63
E. dilatata	10.00	20.00	0.00	0.00	6.98
L. cardium	0.00	0.00	10.00	7.69	4.65
O. olivaria	10.00	10.00	0.00	0.00	4.65
L. teres	0.00	10.00	0.00	0.00	2.33
L. recta	0.00	10.00	0.00	0.00	2.33
U. imbecillis	0.00	10.00	0.00	0.00	2.33
A. ligamentina	0.00	10.00	0.00	0.00	2.33
Q. nodulata	0.00	0.00	0.00	7.69	2.33
A. confragosus	0.00	0.00	0.00	7.69	2.33
Total samples	10	10	10	13	43

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13. ABSTRACT *(Maximum 200 words)*

In 1988, the U.S. Army Engineer District, St. Louis, initiated a monitoring program to analyze the effect of commercial navigation traffic on freshwater mussels (Mollusca: Unionidae), especially the endangered *Lampsilis higginsi*, in the upper Mississippi River (UMR). Preliminary studies were conducted in 1988, and detailed studies were initiated in 1989 and continued until 1994. In July 1994, the last year of this study, qualitative and quantitative data (0.25 m^2 total substratum samples) were collected at the following locations: Pool 24 (River Mile (RM) 299.6), Pool 17 (RM 450.4), Pool 14 (RM 504.5), Pool 12 (RM 571.4), and Pool 10 (RM 635.2, main channel). This research was funded by the U.S. Army Engineer District, St. Louis, to assess the effects of existing and projected future increased navigation traffic levels on freshwater mussels, including the endangered Higgins eye mussel, *Lampsilis higginsi*.

A total of 26 species of bivalves were collected, including two exotic species, the Asiatic clam, *Corbicula fluminea*, and the zebra mussel, *Dreissena polymorpha*. During this study year, zebra mussels were still a minor component of the bivalve assemblage; density ranged from 0.27 ± 0.13 at RM 299.6 to 8.2 ± 1.29 individuals/m^2 at RM 504.8. Based on quantitative samples at five beds, species diversity ranged from 1.78 to 2.28, and total species

(Continued)

14. SUBJECT TERMS

Endangered species	Mussels	Traffic
Lampsilis higginsi	Navigation	Uniondae

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richness ranged from 16 to 20. The percentage of native bivalves less than 30-mm total shell length, evidence of recent recruitment, was approximately 30 at all sites except in Pool 10 at RM 635.2 where it was only 12.8. The percentage of species that were evidence of recent recruitment ranged from a low of 43.7 at RM 299.6 to 60.0 at RM 571.5. Density of native mussels ranged from a low of 16.2 ± 1.90 (Standard Error, SE) at RM 299.6 to a high of 51.5 ± 4.98 at RM 504.8.

One *L. higginsi* was collected using qualitative methods at the bed in Pool 17. At RM 504.8, *L. higginsi* represented 0.76 and 0.44 percent of the qualitative and quantitative collection, respectively. *Lampsilis higginsi* was not found at RM 571.5, but it was collected using quantitative methods in Pool 10. Analysis of *Amblema plicata plicata* from all pools clearly indicates that mortality takes a heavy toll on individuals approximately 90 mm long or greater. Mortality of *Leptodea fragilis* takes many individuals before they reach average adult size. The commercially valuable *Megalonaias nervosa* ranges from 30 to 90 mm long, which indicates steady, moderately strong recruitment to the population.

As with previous study years, biotic conditions appeared stable at these beds. No adverse effects caused by movement of commercial vessels were found. Density, evidence of recent recruitment, and population demography of dominant populations appeared to be unaffected by the high water of 1993.